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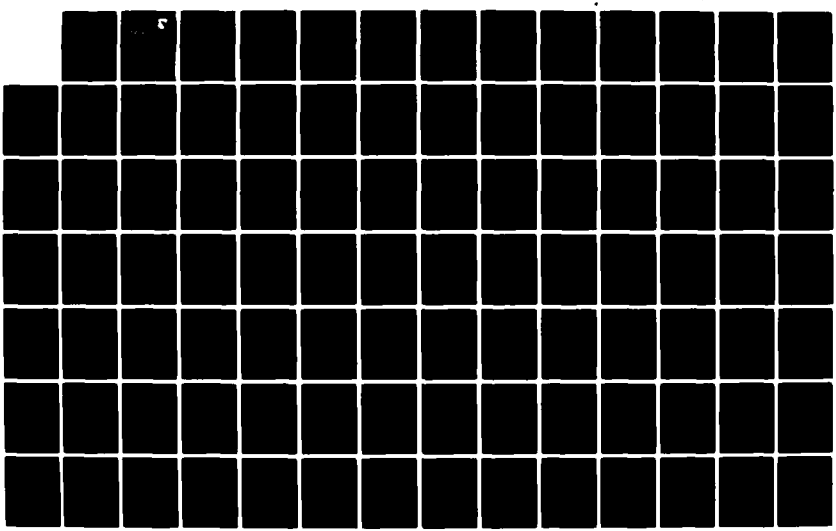

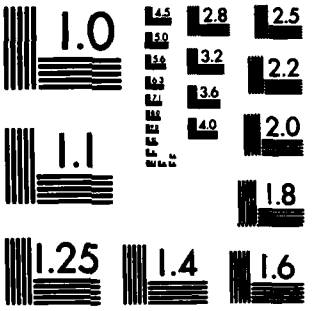

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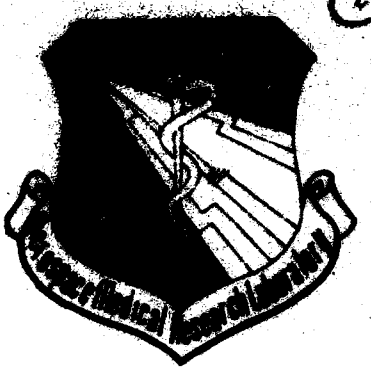

REGISTER OF RESEARCH IN PROGRESS ON MENTAL WORKLOAD

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JULY 1982

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TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-82-42

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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Operator Workload
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents current research on operator workload. The register was compiled from responses to a questionnaire data form sent to 76 scientists who are active in basic and applied workload research. The six sections of the register include name and key-term indexes, current project descriptions, listings of workload laboratories and potential sources of research support, and a bibliography of significant publications in the area.

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PREFACE

This report is an international register of current basic and applied research efforts on the mental workload of human operators. The work involved in compiling and editing this report was performed in support of AFSC Project 7184, Man-Machine Integration Technology for the Air Force, by the Air Force Aerospace Medical Research Laboratory (AFAMRL), Human Engineering Division, Wright-Patterson Air Force Base, Ohio 45433.

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INTRODUCTION

This volume is the second in a periodic series of reports of current research on operator workload. As in any highly active area of scientific investigation, progress toward the understanding of mental workload is impeded by a less than adequate system of professional communication. Lengthy publication delays, the wide variety of journals and technical report sources in which workload research appears, and the sheer volume of data being produced substantially detract from the crucial flow of information among scientists and users of workload research. These problems are ultimately reflected in a tendency for needless duplication of effort and a reduction in the efficiency with which research findings are translated into equipment design and training solutions.

The Register of Research in Progress on Mental Workload was conceived as one means by which communication and cooperation among researchers could be improved. Essentially, the register is intended to act as a directory to workload scientists and their projects. For a second year, data forms were sent to individuals selected on the basis of known previous activity in the area. Seventy-six persons currently engaged in workload research contributed responses. The information provided by the researchers was compiled along with the data obtained in the 1980 edition to produce the six sections comprising the 1982 register.

The first two sections provide a name index and a list of key terms which may be used to facilitate access to more specific information on individual research efforts. The third section contains data on each researcher's affiliation, mailing address, and telephone number. In addition, each entry is accompanied by current project descriptions provided by the respondent. The fourth section is a listing of laboratories engaged in workload research. The final two sections contain general information deemed to be of possible use to both present and future researchers in the area. The fifth section lists organizations which, according to the respondents, have interests in workload research and may be sources of funding for such efforts. The sixth section contains responses to a request to list those publications, reports, and books which have made the most significant contributions to the understanding of mental workload.

Present plans call for the register to be updated and published on a semi-annual basis. Comments on the format of the register, potential improvements, and suggestions concerning the inclusion of significant research efforts not represented in this edition are welcomed. Please address any correspondence to:

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SECTION II

KEYTERM INDEX

A fixed list of keyterms was provided on the data form. Respondents are listed under all keyterms which they indicated as being descriptive of their research interests.

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Hopkin, V. David
Moray, Neville P.
North, Robert A.
Rasmussen, Jens
Rohmert, Walter
Sanders, Mark S.

Weapons Systems

Brictson, Clyde A.
Butterbaugh, Larry C.
Christensen, Julien M.
Crabtree, Mark S.
Crawford, Billy M.
Donnell, Michael L.
Fregley, Alfred R.
Gabriel, Richard F.
Gomer, Frank E.
Gopher, Daniel
Jahns, Dieter W.
Jex, Henry R.
Lane, Norman E.
Linton, Paul M.
North, Robert A.
O'Donnell, Robert D.
Parks, Donald L.
Qualy, Judi
Schiflett, Sam G.

Section III

CURRENT PROJECTS

This section contains an alphabetically arranged list of researchers. Each entry includes the researcher's primary organizational affiliation, address, and telephone number, and is accompanied by brief descriptions of one or more current mental workload research activities of the respondent.

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STRESS AND PERFORMANCE IN THE FLYING TRAINING ENVIRONMENT

The objective is to investigate stress in the flying training environment with particular interest directed to stress of simulated flight and subsequent stress of airborne events. Experiments have been planned which (1) allow for quantification of stress experienced in various modes and phases of surface attack training, (2) help determine the interaction of instructor techniques and student stress, and (3) provide a clearer picture of the relationship between stress, learning, and performance in surface attack training.

Three studies will examine (1) physiological indices of stress in A-10 surface attack training, (2) the effect of IP teaching style on student stress, and (3) the effect of combat experience on stress response to simulated A-10 scenarios.

STRESS UTILIZATION/REDUCTION IN FLYING TRAINING

Previous research established the utility of catecholamine excretion as a metric to assess stress in pilot training. The objective of the present work unit is to determine patterns of stress response in pilots exposed to varying levels of workload/stress in both aircraft and simulated flight scenarios.

Four experiments will be conducted, each of which will assess patterns of stress response as indicated by a selected set of hormones, neurotransmitters, and their metabolities. Urinalysis will be employed. These experiments address (1) stress response of pilots in simulated high threat environments, (2) relationship of psychophysiological and biochemical stress responses, (3) biochemical response profiles to different stressors, and (4) stress in flight line emergencies.

ASSESSMENT OF WORKLOAD AND PREDICTION OF PERFORMANCE BY COMBINED TECHNIQUES

The objective is to develop and implement combined behavioral and psychophysiological techniques for measuring pilot attention and task load during flight simulation. Ultimately these combined techniques will be used to optimally structure flight simulation training programs and equipment.

A series of laboratory studies will be conducted in order to effectively develop and refine the combined psychophysiological and behavioral measures. These studies will use a simplified flight simulation type behavioral task with task difficulty varying as a function of primary and secondary task difficulty.

A series of related flight simulation studies at AFHRL will also be conducted in order to transfer the laboratory findings to the flight simulation environment.

AIRCREW PERFORMANCE ASSESSMENT SYSTEM FOR THE C-5 SIMULATOR

The objective is to develop and implement an aircrew performance assessment system for the C-5 flight simulator. The performance measurement system shall provide a means by which valid, reliable, objective/quantitative mission performance data may be obtained for C-5 aircrew members. These performance data shall be obtained for all mission essential/critical performance items. The system as specified shall constitute a feasibility demonstration or experimental prototype model. As such, it shall provide a means for exploring alternative performance measurement strategies and determining the relationship between measured performance in the simulator and the aircraft.

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SUBJECTIVE ASPECTS OF PHYSICAL AND MENTAL LOAD

During the past 20 years, we have been carrying out studies on various subjective aspects of workload. Most of the studies have concerned performance of, and perceptual responses to, heavy physical work, although subjective effort and difficulty perceived during mental tasks have also been dealt with. We have been using three different kinds of stress indicators or "effort variables": perceptual, performance, and physiological, which compliment one another. To arrive at a full understanding of man at work, we must study subjectively perceived differences not only over the whole range of working conditions, but also in relation to preferred intensities of effort, adaptation levels, stress conditions, etc., and observe how subjective changes at these levels are related to performance, physiological indicators, and measurements of working capacity (Borg, 1971).

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METHODS TO ASSESS PILOT WORKLOAD AND OTHER TEMPORAL INDICATORS OF PILOT PERFORMANCE EFFECTIVENESS

A systematic approach to define, measure, and describe how certain pilot-related variables influence carrier landing performance during sustained operations is briefly outlined. Previous exploratory research on the interrelations between psychophysiological variables, pilot experience, and performance is described. Pilot work activity, mood, and sleep are identified as indicators of a pilot's temporal state of readiness. A field study design and techniques to measure and describe temporal readiness during prolonged flight operations are provided to demonstrate the methodology in an operational environment. Potential applications of the research are discussed along with the future role of temporal, psychological, and other moderator variables in estimating pilot flight status.

AIRCREW PERFORMANCE RESEARCH OPPORTUNITIES USING THE AIR COMBAT MANEUVERING RANGE (ACMR)

Three years of aircrew performance measurement related to air combat effectiveness using the Navy's Air Combat Maneuvering Range (ACMR) are presented as evidence of ACMR's research potential. Performance assessment methods used to evaluate pilot proficiency are described. The aircrew assessment methods have been used to identify squadron performance differences, evaluate competitive exercises, and provide diagnostic training feedback to operational users. The use of continuously recorded quantitative measures from systems such as ACMR should stimulate more aircrew performance field research ideas. The availability of objective performance criteria promises to be of substantial benefit to both the operational user and the research community in such areas as pilot selection and training, fleet combat readiness, and pilot workload and stress.

PREDICTION OF PILOT PERFORMANCE: BIOCHEMICAL AND SLEEP-MOOD CORRELATES UNDER HIGH WORKLOAD CONDITIONS

A preliminary study of pilot performance, blood chemistry, and sleep/mood patterns during prolonged periods of carrier operations indicated that changes in pilot metabolism and subjective moods can be related to variations in pilot landing performance. A statistically significant multiple R of .81 ($n = 26$, p F .01) was obtained with four predictors. In a separate study, pilot sleep patterns for a one-week period were related to landing performance scores. Pilot intersleep intervals were highly correlated with day landing performance and found to be significantly different than those of nonflying personnel.

MEASURES OF PILOTS' TEMPORAL STATES OF READINESS

This research follows up previous results with more refined data collection procedures and instruments and integrates measures of a pilot's temporal state of readiness (sleep, mood, workload) with other pilot centered measures. Studies of two stress environments were undertaken: (a) carrier deployment, and (b) carrier landing qualification (CQ). Pilots from three attack squadrons embarked on the USS Kennedy (CV-67) during a recent Mediterranean deployment were the subjects for Phase 1 of the research program. Data were collected on daily activities for three major periods of time: a baseline nonflying period; a follow-up normal flying period; and a 72-hour high workload period of continuous flight operations. Daily activity data on pilot workload (flying and administrative) sleeping, eating, exercise, and mood as well as pilot landing performance for the entire cruise were collected and analyzed. Findings of interest indicate that pilot workload averaged 13 hours per day with 57 percent of the time spent on flight-related activities. When flying increased, squadron administrative work was reduced proportionally. No group sleep pattern disruptions were noted although sleep duration rose as flight activity increased. More short sleep episodes (naps) during flight periods account for this increase. Performance findings were remarkable for their consistent high levels, especially in terms of night carrier landing performance.

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SOME EFFECTS OF TASK AND WORKSPACE DESIGN TRENDS ON CORRELATES OF JOB SATISFACTION AMONG TELEPHONE SWITCHBOARD OPERATORS

Operators of cordless switchboards report dissatisfaction with their job and perform less efficiently than operators of cord boards. To explore possible causal factors, 15 operators participated in a psychophysiological study of both working conditions. Cord operators were found: (a) to carry a consistently heavier workload of concurrent calls; (b) to be dramatically more responsive to diurnal fluctuations in call-traffic level, while maintaining more stable "caller waiting times" and "effective call connections"; (c) to exhibit this advantage without displaying higher levels of physiological stress; and (d) to display consistently higher levels of psychological well being. It is concluded that the cord operators' greater job satisfaction derives mainly from the substantial advantages their flexible system provides them in attaining and maintaining a high quality service.

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WORKLOAD PROBLEM ASSESSMENT

The Air Force function for this effort is to research operational aircrew workload and advanced methods for assessing the workload expected in future vehicles. A problem has occurred due to the neglect in developing assessment methods which are sensitive to workloads in advanced control and display systems. The objective is to maintain familiarity with workload assessment technology, to have total awareness and understanding of current operational workload problems, and to study innovative workload assessment methods for their applicability to crew systems engineering. This effort will contribute knowledge needed to fully understand operational workload problems such that the crew systems interface areas requiring further study can be identified. Operational crews from the major commands were interviewed in FY80 and workload related flight problems identified. A data base of operational workload problems was created in order to identify crew system problems that should be addressed in the development of future vehicles. As a result of this work effort, existing workload problems are identified for existing system operation, allowing for their study and resolution prior to their repetition in future systems (AFWAL-TR-80-3011). Such insight into current workload problems and the awareness of improved workload assessment methods will result in better and more cost-effective methods of evaluating crew workload as part of the crew systems development process. This work effort has been completed.

CREW SYSTEM DESIGN AND EVALUATION METHODOLOGY

The Air Force function supported by this work effort is the research and development of the crew system interface for advanced airborne weapon systems. As aircraft missions have become more complex, so has the crewstation design. The point has been reached where the crew system interface and its optimization can significantly impact the pilot's ability. This means the crewstation must be designed as an integral unit and that a variety of design evaluations are necessary to assume the design is optimized. In other words, the total evaluation must address all the issues (e.g., workload, reliability, performance, fatigue, task allocation, etc.), not just one or two. The objective is to establish and maintain an awareness of the complexity of total crew system design and evaluation and to become familiar with methods that exist throughout the R&D community, and to study innovative evaluation methods for their applicability to the crew system engineering process. This in-house effort will consist of literature reviews and data base searches in order to document the range of design and evaluation methods, their constraints for application, and their value as a design or evaluation tool. The crew system engineering process will be documented in TR format in FY81. Periodic, regular communications will occur with other DoD organizations in the area of crewstation evaluation techniques. As a result of this work effort, USAF weapon systems will be more fully evaluated from the position of the crew system interface. By

identifying the range of design issues and methods by which to resolve them, better and more cost-effective evaluations can occur.

TAACE WORKLOAD PREDICTION

This contracted effort applied an analytic method known as the Controls and Displays Evaluation Model (CODEM) to flight deck avionics improvements which resulted from AFWAL/FIGR's Tanker Avionics and Aircrew Complement Evaluation (TAACE) Program. Specifically, CODEM was used to evaluate the capability of the TAACE improvements to perform the Rendezvous and In-Flight Refueling segments of the KC-135 mission. (TAACE data were utilized because the underlying intent of this contract was to apply CODEM to a previously, independently evaluated design for the purpose of validating the CODEM concept and sensitivity. This evaluation will occur independent from this effort.)

TAACE, which supported the USAF KN-135 Modernization Program, sought to establish the design criteria for the controls and displays of the improved flight deck avionics in the event the crew of the KN-135 is reduced by eliminating the navigator. The study involved the analysis of the new flight deck hardware designed for the KN-135; the application of Northrop's CODEM program to generated crew task complexity, or workload, profiles, and the identification and validation of changes which, according to the profiles, would further reduce the crew's workload.

The CODEM results indicated that the flight deck of the modernized KC-135 aircraft can be operated satisfactorily in the Rendezvous and In-Flight Refueling segment of a tanker mission with only a pilot and a copilot. The study also established that, on the basis of the CODEM analysis, the new flight deck avionics equipment elements did not cause unacceptably high crew workloads during the mission segment studied. The technical work has been completed and a Technical Report is being processed for publication.

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DEVELOPMENT OF A SHORT-RANGE AIR DEFENSE SIMULATION FACILITY AND A CREWMAN PERFORMANCE DATA BASE

BACKGROUND

Studies are currently being undertaken to establish air defense command and control system requirements essential to the accomplishment of the air defense mission and to evaluate equipment performance and doctrinal concepts. An important, critical part of the above system requirements is information concerning Short-Range Air Defense (SHORAD) weapon system personnel detection and recognition capabilities. This information is, however, difficult to obtain because of the high cost of live aircraft support and of the nonavailability of foreign aircraft.

During the interval of 1964 through 1976, research aimed at developing a data bank concerning the capabilities of operators of forward area air defense weapons to detect, identify, and estimate the distance of low-flying aircraft was conducted. The studies had to be conducted, however, in a part-task evaluation environment. That is, each of these critical tasks was studied in isolation from the other components of the total operational sequence. Part-task research only was conducted because techniques for measuring the effectiveness of the total engagement sequence were not economically feasible. As a result, there is a lack of information concerning an operator's abilities in performing part-task components when they are embedded in whole-task performance requirements.

RESEARCH

The Army Research Institute has initiated a research program oriented toward the development of a facility which realistically simulates the SHORAD engagement environment and the generation of a data bank of information concerning operator performance.

Past Research

The effort thus far has consisted of a paper-and-pencil feasibility study of the applicability of low-cost simulation for presenting the SHORAD environment. In Task 1, parameters which must be included in the simulation of the SHORAD engagement environment were identified. During Task 2, low-cost simulation approaches were evaluated for their relevance for the SHORAD environment. Three sets of data that will be necessary to collect when assessing operator performance capabilities were identified in Task 3. Instrumentation to gather data was also detailed.

Present Research

The present research effort will occur over the course of three years. Year 1 research is directed at fabricating a scaled dynamic flying model aircraft facility and evaluating the validity of the simulation. The orientation of the research in Year 2 will be primarily to gather baseline data. Year 3 research will have the main purpose of investigating the effects of cueing and early warning on detection and recognition.

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DEVELOPMENT OF ADDITIVE WORKLOAD SCALES

Fundamental Measurement theory is being applied to develop additive scales of mental workload. A technique has been developed to equate the workload of different types of tasks without making arbitrary scaling assumptions about the relationship between task performance and mental workload. The additivity assumption is being tested both in a secondary task framework

and in a subjective scaling framework. Currently, a battery of tasks is being evaluated.

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SUMMARY OF ON-GOING RESEARCH

The major focus of attention for both basic research and exploratory development for the Crew Performance Branch is aimed at developing and applying means to assess the stress, fatigue, and workload effects on crew performance in adverse operational conditions and environments. Both in-house and contract activities are involved. The basic research efforts are performed as a part of the program of the Air Force Office of Scientific Research. The exploratory development activities are being undertaken in concert with the Workload and Erognomics Branch of the Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio.

Current efforts include development of subjective self-report scales of perceived operator fatigue for aircrew and groundcrew; subjective self-report scales of perceived operator anxiety states; electrophysiological techniques for the assessment of attention lapses associated with changes of alertness for aircrew; electrocardiographic techniques for in-flight assessment of pilot workload; and methods for assessing the field applicability of various promising laboratory methods of assessing workload presently under development at the Air Force Aerospace Medical Research Laboratory. Basic research efforts are presently directed towards examination of the components of complex decision-making tasks for their individual component susceptibility to the effects of stressors associated with varying demand schedules and unusual work/rest schedules; development of metrics based on eye-blink and eye movement which can be used to index lapses in operator attention and the onset of fatigue likely to effect decision-making and information processing of the type required in the operation of military aircraft; examination of the potential for time series analysis of electro-encephalogram and electroculogram data for indexing a pilot's ability to perform information processing and decision-making, particularly as it is effected by repeated sorties within a given day; and examination of the potential of sequential optimal control models for becoming a means to index piloting behavior in the presence of high cognitive processing workload demand under conditions of repeated missions in a single day.

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COMMUNICATIONS WORKLOAD PROJECT

Most workload assessment techniques suffer from a number of shortcomings that can be attributed to the lack of validity and reliability data associated with the techniques, possible difficulties in directly measuring mental events, lack of operational applicability, the need for additional equipment in space-limited environments, and a variety of other ills. Even secondary tasks, which are the most widely used methodology for objective measurement of workload, are often intrusive, unrealistic, and poorly accepted by pilots. A means for overcoming these difficulties may be found in a task that is imbedded in other activities that are already a part of the operator's normal duties. Radio communications activities appear to be amenable to such application because they embody many properties of a good workload measure. Information theoretical analysis and pilot opinions indicate that communications activity can be broken down into individual tasks with specifiable levels of workload. The results of a simulation study indicate that human performance on certain communications tasks is indeed sensitive to primary task difficulty. Future efforts will be directed toward the validation of these results in high fidelity simulations. The ultimate goal of the communications workload project is the development of a standardized set of communications tasks that can be used as embedded secondary tasks for workload assessment at all stages of system evolution.

SECONDARY TASK DEVELOPMENT PROJECT

Some secondary tasks may be more sensitive than other secondary tasks to the workload imposed by specific primary tasks. It is possible that secondary tasks which share the same mental capacity or resource as the primary task may be more sensitive than those that tap separate resources. On the other hand, those that tap the same resource may intrude on the primary task. Therefore, this project was directed toward determining the best combinations of primary and secondary tasks. Much of the researach will be empirical. For example, the memory update task was developed as a secondary task in which the amount and the rate of information presented to subjects could be varied. Analysis of performance scores and SWAT (Subjective Workload Assessment Technique) ratings indicated that both variables were effectively manipulated. Future studies will concentrate on combining this task with other tasks and determining its sensitivity to workload.

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COMMAND CONTROL WORKLOAD

Workload assessment is included in evaluations of the adequacy of human engineering in operational Air Force Command Control Systems. Subjective workload scales are included in crew opinion surveys to supplement direct observation and measurement of primary task performance. Primary task measures include frequency and duration of crew interactions, telephone/radio communications, display viewing and adjustment, and checklist use. Indirect measures of task loading are derived from counts of the classes of information input/output identified in functions analyses.

Video/audio tape recordings facilitate assessment of workload indicated by overt behavior. Correlational analysis is used to obtain estimates of the amount of variance in judged workload accounted for by various task activities. Results are used as a partial basis for recommended human engineering design improvements including changes in procedures, workplace layout, performance aids, task allocations, etc.

SYNTHETIC DATA SYSTEM

Industrial and engineering methods have been evaluated to determine feasible candidates for adaptation to Air Force crew workload assessment and allocation. It was determined that a combination of time synthesis methods and standard data systems was most appropriate. However, significant development is required. Deficiencies of systems currently used for industrial purposes are: (1) lack of consideration for divided attention effects, and (2) inadequate data on performance time distributions. Data were collected on motor-perceptual tasks, perceptual-mediation tasks, display reading and communication as a first step toward data base development. Results indicate that a "Synthetic Data System" is feasible and that it could be combined with computer system simulations and computer-aided design to form a viable approach to workload issue resolution both during and after system development. Contractual support for this effort was provided by Professor James Buck, formerly of Purdue University, now at the University of Iowa. Documentation is being prepared for this effort.

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DEVELOPMENT AND TRANSFER OF TIMESHARING SKILLS

Performance on two different task combinations was examined for evidence that timesharing skills are learned with practice and can transfer between task combinations. One combination consisted of two discrete information processing tasks, a short-term memory task and a classification task; the other consisted of two identical one-dimensional compensatory tracking tasks. Three groups of 16 subjects were employed in the experiment. The first received dual-task training on both combinations; the second received single-task training on the discrete-task combination and dual-task training on the tracking combination; the third received dual-task training on the tracking combination only. Evidence for distinct timesharing skills was found in both combinations using a new technique designed to separate improvements in timesharing skills from improvements in single-task performance. Transfer of timesharing skills also was found. Several fine grained analyses performed on the data from the discrete task combination and a control theory analysis of the tracking data indicated that skills in parallel processing were learned in each combination and transferred between them.

INDIVIDUAL DIFFERENCES IN DUAL-TASK PERFORMANCE

Eleven right-handed males participated in an experiment examining individual differences in multiple-task performance. Three task combinations were used in the study. The first was composed of a memory task and a classification task. The second consisted of two identical one-dimensional compensatory tracking tasks. The third was a dichotic listening task. On day 1 of the experiment, the subjects practiced each task alone. On days 2, 3, and 4, they performed primarily under dual-task conditions. Periodically, however, dual-task practice was interrupted to reassess single-task performance. All dual-task data were analyzed first to determine when stability occurred. Each subject's stabilized data from the tracking-tracking and memory-classification combinations then were corrected for the appropriate single-task baseline. Finally, the subjects were grouped according to which of three response strategies they used to perform the memory-classification task combination. These strategies were a massed strategy (in which the subject would emit a series of responses to one task before responding to the other), an alternating response strategy, and a simultaneous response strategy. A two-way repeated measures MANOVA conducted on the stabilized adjusted data indicated both a significant effect of trials and groups. Possible sources of the between-group differences are discussed.

RESIDUAL ATTENTION AS A PREDICTOR OF PILOT PERFORMANCE

Sixteen student pilots performed a task combination consisting of a choice reaction time task at 1, 2, and 3 bits of information and a one-dimensional compensatory tracking task. Cross-adaptive logic was used to keep performance on the tracking task constant, casting the between-subject variance into the choice reaction time task. Scores on this combination were correlated with performance on flight checks administered after 10, 20, and 30 hours of flight training. The multiple correlation between performances on the flight checks and the task combination increased as the students progressed through flight training. The usefulness of residual attention as a predictor of pilot performance is discussed.

A COMPARISON OF SINGLE- AND DUAL-TASK MEASURES
TO PREDICT PILOT PERFORMANCE

An experiment comparing the predictive validity of single- versus dual-task measures is reported. Fifty-seven males received two trials on each of two identical one-dimensional compensatory tracking tasks. The subjects then attempted to perform the tasks concurrently for 25 trials. Finally, they performed each task alone for one trial. The subjects then were given a short basic flight course consisting of ground instruction and practice in a GAT-2 simulator. After completing the course, the subjects were asked to perform four repetitions of a descent, a descent followed by a stall, and a level turn. Performance was scored by an instructor and an observer. Performance in the simulator then was correlated with performance on each tracking trial. The predictive validity of the early single-task scores decreased with practice while the dual-task validity increased throughout the testing session. However, the predictive validity of the late single-task scores was almost as large as that of the late dual-task scores. Possible explanations for the results are given.

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MEASURING SYSTEM EFFECTIVE OPERABILITY

A technique for measuring the effective operability of major air systems [The Mission Operability Assessment Technique (MOAT)] has been developed. MOAT combines the Pilot Task Inventory (PTI) approach with Multi-Attribute Utility Theory (MAUT), which is used to hierarchically organize and determine the importance of tasks and Psychological Measurement Theory and Scaling techniques, in particular Conjoint Measurement and the Delta Method of Scaling. System Effective Operability is defined as the weighted sum of the Operabilities of the individual tasks. The weights reflect the individual task's criticalities as well as the importances of the various aircraft phases, subphases, and duty levels which are bases for the hierarchical organization of tasks. The operability of an individual task is an additive combination of workload and technical effectiveness. Measurement

theory and scaling have been utilized to show that an additive combination is appropriate and to determine the underlying scales. When computerized, MOAT allows the rapid identification and determination of the relative magnitudes of system operability deficits.

A DECISION-ANALYTIC AID FOR AVOIDING COGNITIVE OVERLOAD

Decisions and Designs, Inc. (DDI), has proposed an approach to workload management that uses a cost/benefit analysis as its underlying principle. The commander or manager of a complex system, such as a submarine or an air traffic control center, is viewed as having a limited cognitive capacity which must be allocated amongst competing demands on his attention. When the total demand exceeds capacity, he must either shed some of his load or run the risk of a breakdown in his performance. Cognitive load can be shed in a variety of ways such as selective attention, task simplification, or responsibility delegation. However, each of these techniques is likely to produce a poorer result than would be expected if the commander's full attention were devoted to the task. Thus, shedding cognitive load involves a cost in that it will produce poorer performance and a benefit in that it reduces the demands placed on the principal decision maker. Using a model of the costs and benefits associated with shedding cognitive load, a computer aid could help a decision-maker determine which of his tasks are most critical. The aid could help determine how and when to delegate responsibility. As necessary, the aid could help allocate a decision-maker's cognitive capacity over the tasks that must be performed. In these ways, the aid could help avoid cognitive overload and enhance an individual's ability to manage a complex technological system.

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TACTILE DISPLAY APPLICATIONS

The evaluation of a new tactile display concept required workload comparisons between visual and tactile display devices and between alternate tactile display designs and modes of operation. Critical tracking and cross-adaptive subcritical tracking tasks developed by Jex et al., have been refined for these purposes. These workload oriented display assessment procedures are part of a program to develop tactile displays for operational helicopter applications.

GENERAL PURPOSE AND SIMULATOR ORIENTED WORKLOAD MEASURES

A long-term research objective is to develop a variety of workload assessment techniques for general use in flight simulator research and other R&D projects bearing on helicopter design and employment by the Army. Approaches under investigation include secondary task time estimation, vocal

measures of stress, primary and secondary task performance in various continuous and discrete tasks, and analytical procedures for task analysis. The goal is to establish a variety of workload measures to support Army aviation by making tactical helicopter crew workload a more predictable and manageable parameter of system design.

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WORKLOAD MODELING

A considerable amount of research has been conducted on workload associated with maintaining the aircraft state vector (i.e., tracking tasks) and workload associated with subystem operation (i.e., discrete tasks). Much of the available data, however, is not in a form that can be readily incorporated into existing computer based workload models. A series of studies is being conducted to develop a data base that can be used to extend the capability of existing mathematical models of human tracking behavior. In these studies, workload associated with manual control of an aircraft's pitch and roll axes is being examined under a number of different environmental and secondary task loading conditions.

WORKLOAD ASSESSMENT

A series of part-task and full-mission flight simulations will be conducted as part of the FAA flight deck certification effort for the Boeing 757 and 767 airplanes. The simulation effort will involve both fixed-base and motion-base research simulators. Objective performance measures and subjective measures will be employed in a direct comparison of workload between crewstations with traditional electromechanical instruments and crewstations with advanced electronic displays. These comparisons will be made under both normal and degraded mode operations.

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SUBJECTIVE WORKLOAD ASSESSMENT

In many applications of subjective workload measurement techniques, practical constraints make it desirable or necessary to delay completion of subjective ratings until some time after actual task performance. This raises a question concerning the possible effects of such delays on the accuracy of subjective ratings. On the basis of the memory literature, it can be predicted that some loss of information will occur at relatively short retention intervals, but little data currently exist that address the specific

relationship between retention interval and accuracy of subjective ratings of workload. A series of studies have been planned to examine the retention interval-workload rating relationship. At present, the first study is underway. In this initial study, subjects perform an information processing task that requires that they update and recall the status of several continually changing categories of information. Subjects complete a subjective workload rating scale either immediately after the task or at one of two retention intervals. Immediate ratings will be used as the baseline to assess the effects of retention interval on the delayed ratings. Results of this first study will be used to structure subsequent efforts.

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INSTRUMENT SCANNING BEHAVIOR AS AN INDICATOR OF PILOT WORKLOAD

This is an investigation of the relationship between an aircraft pilot's visual scanning of instruments and his level of mental activity during a simulated approach and landing. This study is motivated by the increasing concern in several areas of man-machine interaction with the effects of changes in manual control and monitoring procedures on mental workload. This concern is particularly keen with regard to airline pilots, air traffic controllers, power plant operators, and personnel in control of large ocean-going vessels, since the cost of error can be quite high in any of these man-machine systems.

Visual scanning behavior plays an important role in each of these systems, since the operator will typically be required to monitor a number of instruments which display system state variables. In each of the above roles, the human acts as a decision maker, a planner, a manual controller, a monitor, and an event detector. His ability to perform these tasks is generally influenced by their nature, number, and temporal arrangement; by his general physical and psychological state; and by the occurrence of unusual or rare events such as mechanical failures, bad weather conditions, etc. Ideally, a human operator's job should be designed in such a way as to require an appropriate fraction of the operator's capacity. To accomplish this design objective, however, the designer must have a method at his disposal of estimating the expended capacity under different conditions. While there exists a number of these methods, none is sufficiently benign and noninvasive to be used in the field (for instance, in an airliner's cockpit in flight). Consequently, we have set out to develop an estimator of mental loading, based on the operator's visual scan pattern.

In the current work, experiments were conducted in a Terminal Configured Vehicle (TCV) fixed-base flight simulator at NASA Langley Research Center. Three NASA test pilots were presented with a piloting task, an arithmetic task designed to vary mental loading, and a side task for calibration of the

mental loading task. The pilot lookpoint was obtained by using a highly modified Honeywell oculometer system, and the pilot's eye scan of the instruments was recorded. The piloting task involved flying a curved Microwave Landing System (MLS) approach from a specified waypoint to touchdown.

The mental loading task was chosen so as not to interfere with the visual scanning of the pilot while providing constant loading during the approach. This was accomplished by having the pilots respond verbally to a series of evenly-spaced, three-number sequences. The pilot was told that he must respond to each three-number sequence by saying either "plus" or "minus" according to the following algorithm: first number largest, second number smallest = "plus"; first number smallest, last number largest = "plus"; otherwise = "minus." The numbers were recorded at 20 second and 10 second intervals. These intervals had been determined empirically to vary mental loading under a similar piloting task.

The workload measuring side task employed two lights, one mounted above the other, placed just outside the pilot's peripheral view above the instrument panel. The lights came on at random intervals between 1 and 3 seconds and remained on for 1 second. The pilot was told to turn the lights off by using a three-position rocker switch on the control grip (moving the switch up turned the upper light off, down turned the lower light off). This was done only when the pilot had time left from performing the primary task of flying the airplane. Thus, the number of correct responses to the lights saved a measure of the residual capacity of the pilot from which a workload index could be calculated.

A computer algorithm has been developed to obtain the first-order, discrete-state, discrete-transition, Markov model for each pilot's scanning pattern. It is assumed that workload is constant within each of the six approach segments since the piloting tasks are essentially constant over each segment. This allows comparison of the instrument transition matrices for each segment with those obtained under different loading conditions. The relationship between visual scanning and workload is given by the change in the elements of these matrices as loading varies. Higher order Markov models may also be used to provide a more accurate description of the processes taking place.

MENTAL WORKLOAD IN DECISION TASKS

The importance of an operator's mental workload in manual control tasks has been increasingly recognized in recent years. As a consequence, a number of mental workload evaluation methods have been developed to serve as system design tools for tasks in which the human serves as a control element or in which he fills a supervisory (monitoring) role. These methods include performance measures, identification of fractional-attention parameters in analytic models, secondary tasks (reserve capacity) techniques, subjective scaling, and measures of correlated physiological variables.

Research is needed to extend the state of the art from the realm of manual control to that of decision making. With the increasingly evident shift of the human's role from that of a manual controller to the executive level of

a decision maker, an understanding of the relationships between the demands imposed by decision making tasks and the resulting cost in mental workload is essential.

Our approach is to construct an appropriate decision task whose level of complexity and difficulty can be controlled in the laboratory. Methods will be developed of measuring and quantifying the decision maker's mental workload in an experimental context. In parallel, the Optimal Decision Model (recently developed in our laboratory) will be expanded to account for task complexity and for the effects of the decision maker's workload level. The workload evaluation techniques will be of two categories: (1) reserve capacity index, and (2) performance measures, in which the decision maker's performance (rate of incorrect decisions, for instance) co-varies with his mental workload. The independent (i.e., experimental) variables include imposed decision rate, processing time requirements prior to decison making (i.e., complexity), number of alternatives, etc. The net objective is the construction of a canonical workload task that is readily calibrated in terms of noninvasive measures.

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The workload assessment techniques used in the design, development, and certification phases of a commercial airplane program address two basic issues--timeliness of crew actions and ease of operation. The crew must be able to complete all necessary tasks with sufficient reserve time to accommodate unexpected events. Further, the mental and physical effort associated with each task must not place undue stress on the crew. Both objective and subjective methods are used to assess the impact of the flight deck design in these areas. Analysis, simulation, and flight test, used singly or in combination, have proven to be effective techniques for addressing a variety of workload problems. Analytic techniques are of particular interest to the aircraft manufacturer since hardware suitable for full scale simulation or flight test is not available until late in the development cycle.

Timeline analysis is the basic means of ensuring that the crew will have sufficient time to accomplish all of their tasks. During design and development, this technique is augmented by subsystems workload assessments which evaluate panel layouts and procedures, and by task-time-probability analyses which permit variations in task timing and crew performance to be examined. All three are comparative methods enabling a new design to be evaluated with respect to an existing airplane or subsystem well in advance of any hardware commitments. Following this phase, the physical aspects of workload, associated with hand and eye motion, are confirmed by observation using mockups, flight simulators, and/or flight test.

The multidimensional nature of what is commonly called mental workload requires assessment techniques which provide attribute profiles, not a

single index. In this regard we have found specialized subjective questionnaires and rating scales to be the most effective means for addressing mental workload. While subjective assessment methods are very useful, they cannot provide information in advance of hardware availability. We are experimenting with information-theoretic estimates of cognitive workload as a means to provide a preliminary evaluation of mental task loading. Such an estimate can provide a common measure for alternative display and control devices, allowing for a tradeoff between them.

Commercial aircraft workload is qualitatively different than that associated with high performance military aircraft. Commercial aircraft development is evolutionary--each new aircraft flight deck draws heavily on past experience. The population of pilots flying commercial aircraft changes very slowly. The fundamental tasks and decisions expected of the flight crew remain largely the same from one vehicle to the next. It follows, therefore, that new workload assessment techniques will not have a radical impact on new designs. The primary benefits to be expected from new assessment methodologies are improved understanding of the basis for particular design decisions and greater efficiency in the design process.

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BIOCYBERNETICS/WORKLOAD

Optimum man-machine sharing and control of increasing information processing loads in high data rate environments will be provided by means of new biocybernetic techniques. The machine operator's psychophysiological responses will be displayed to machines noninvasively, on line in real time via an automated, adaptive feedback loop. Research emphasis will be given to coding of brain-evoked potentials by electrophysiological and neuriomagnetic means. The brain wave signatures determined across a broad spectrum of sensory, cognitive, and motor activities will serve as templates for developing new neurologically-based metrics of human operator performance. This will assist in identification and prediction of workload factors that influence both the design and operation of crewstations developed for critical training and operational missions.

This program is supported by intramural and contractual efforts at the Aerospace Medical Research Laboratory under Col. Robert O'Donnell to improve man-machine system design and under Andrew Junker in control theory analysis; and at the Air Force School of Aerospace Medicine under Dr. John Courtright in workload evaluation in multistress environments. The Air Force Office of Scientific Research extramural program is managed by Dr. Alfred R. Fregly.

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THE USE OF MENTAL PROCESSING TIME FOR THE EVALUATION OF EADI FORMATS

Integrated displays are commonly evaluated by dynamic tests in flight simulators using secondary task performance measures and subjective reports as the basis for evaluation. Both of these measures are of questionable validity when applied to mental workload quantification because of test artifacts, biases, etc. This project evaluated an alternative approach that has resulted from several years of mental workload research at the Douglas Aircraft Company. In this approach mental workload is defined as the conscious mental processes involved in work and quantified as the time required to perform the mental processes. Three versions of an EADI were evaluated by means of discrete tests of the time required for subjects to obtain various kinds of quantitative and qualitative information from static CRT displays. The results indicate that this is an effective means of evaluating alternative display formats during early design phases.

MENTAL WORKLOAD QUANTIFICATION IN A CONTINUOUS TASK SITUATION

The purpose of this current project is to investigate objective methods of quantifying mental workload involved in obtaining information and making decisions from integrated displays. It is a follow-on to a previous investigation of the use of mental processing time measures to evaluate integrated displays in a discrete task situation. In the present project, subjects are given a flight plan to follow using controls and a dynamic CRT display of flight parameters. The mental processing time required to obtain information and make decisions will be measured by the method of subtraction and used to quantify the mental workload involved in alternative display formats.

PUPILLOMETRIC MEASURES OF MENTAL WORKLOAD

A recently completed study evaluated the use of pupillometer (Gulf & Western Applied Science Laboratories Model 1060-SRP) to assess mental workload. Subjects were given three levels of mental arithmetic under two conditions of manipulated stress in order to isolate purely automatic effects from central processing factors. The results are being analyzed.

PHYSIOLOGICAL INDICES

The efforts of this project are focusing on two major categories of physiological measurement. Electroencephalographic (EEG) and electrooculographic (EOG) measures are being researched, and developed as potentially unobtrusive indices of aircrew mental workload. A brief listing of research topics is

given below with a description of the future direction for development. The laboratory for EEG and EOG recording is just becoming operational, and directions for future development may change dependent on what measures prove useful for operational aircraft. Topics currently under study include:

1. Event Related Potential (ERP), P300 and P165. During simulated flying, ERPs will be elicited by probe stimuli which are aural warning events.

2. Iospotential Contour Mapping of Scalp Voltage Levels. Employing multiple electrode arrays, the contour mapping strategy of mental workload research attempts to develop concepts and metrics for describing focal brain activity.

3. EOG-Vergence Angle Measurement. Measurement of vergence angles of pilots with EOG techniques may permit an unobtrusive measurement of external vision in an operational aircraft. Under some circumstances, the percent time available for external vision (eyes outside the cockpit) may index overall cockpit efficiency.

4. EOG-Eyeblink. Eyeblink levels are being assessed as indices of workload during selected aircraft mission segments. Past efforts have investigated various general physiological responses such as heart rate and heart rate variability, pulse pressure, pulse volume, etc.

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Presently preparing a chapter on mental workload in a forthcoming textbook on Military Aviation Psychology for the Department of Defense of the Federal Republic of Germany.

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PHYSIOLOGICAL MONITORING AND MANNED SYSTEM PERFORMANCE

Pilot workload considerations are beginning to have a distinct cognitive emphasis, due to changes that are occurring in display formats and operating procedures. Consequently, new techniques for assessing workload must be developed that are more sensitive to fluctuations in attentiveness and in the capacity to time-share among several system demands for processing, decision making, and action.

A flight simulation experiment was conducted in which pilots were trained to follow a commanded flight profile and maintain airspeed while concurrently performing threat avoidance and target acquisition tasks. Two types of brain electrical activity, event-related potentials (ERPs) and the "on-going" electroencephalogram (EEG), were analyzed in response to direct manipulations of difficulty in executing commanded flight maneuvers. Because of these manipulations, the difficulty of time-sharing was influenced indirectly. Both workload level and continued experience with the flight simulation tasks affected the magnitude and latency of the P_{300} component of the ERP, as well as the distribution of the EEG power. These findings support the concept of multidimensional processing resources and the distinction between controlled versus automatic modes of processing.

The results of this investigation are encouraging. They suggest that a physiological method used to evaluate mental workload in laboratory settings may be applied successfully, in at least some instances, to situations in which individuals perform operationally relevant tasks.

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A GENERAL APPROACH TO THE MODELING OF TIME-SHARING BEHAVIOR

Human behavior under time-sharing conditions has been conceptualized within a framework inspired by concepts and methods from microeconomy, drawing an analogy between a manufacturer producing one or more products and a person with limited resources performing one or more tasks (1,2). This approach has been used to discuss possible interpretations of dual-task performance wherein concepts such as task difficulty, demand, resource efficiency and resource allocation have been clarified and defined. Special attention is devoted to the interaction between task characteristics, utility consideration, and voluntary control of resources. A survey of the literature and an analysis of existing models of human capacity have led us to outline a multiple resource approach in which the human processing system is assumed to have a number of mechanisms, each having its own capacity.

Our goal to study the joint effects of difficulty parameters and allocation policy resulted in the development of special experimental techniques to manipulate task priorities in concurrent performance. Response surface design has been employed to enable economical experimental design. Results have been analyzed in terms of families of operating characteristic functions. Each function within a family depicts the tradeoff of performance between two concurrently performed tasks for one condition of task difficulty, when resources are allocated in different proportions between the tasks. Experimental tests of these ideas have been conducted using two-dimensional pursuit tracking tasks. These experiments lend support to the theoretical approach and demonstrate the utility of the methodological techniques.

Within this general framework, our experiments during the past year were designed to substantiate some of the ideas suggested in the earlier work, clarify the notion of multiple resources, and test the advantages and disadvantages of such an approach as compared with alternative interpretations of time-sharing interference. Two main studies motivated by the results of the first group of tracking studies were completed. In one experiment, pursuit tracking was paired with binary classification tasks. In another experiment tracking was performed concurrently with variants of a data entry task that required the typing of letter codes.

The first experiment was designed to test the possibility that although vertical and horizontal tracking may in many instances not compete for allocation of common resources, their coordination in joint performance taxes some other mechanisms. This involvement of a coordinating mechanism may not be relevant to tracking performance, yet appear in the performance of a third task. To test this hypothesis, we had subjects make binary classification of digits while tracking. To guard against possible effects of peripheral vision, digits were presented with a square that served also as the control symbol or the target symbol for the tracking task. Memory load was manipulated between subjects. Four conditions of tracking were used: single axis, dual axis, dual axis with feedback indicators, and dual axis with feedback indicators and unequal priorities on the two axes. Experimental results failed to reveal the existence of a coordinating resource. Similar decrements in binary classification and tracking performance were observed under single-axis and dual-axis tracking conditions. The additional requirement to allocate resources between tracking axes in unequal proportions also failed to affect classification performance. We have, thus, concluded that dual-axis tracking is probably not more costly than single-axis tracking in terms of any resource which is not used directly by tracking. An interesting outcome was the overall small deficits that were observed on both classification and tracking tasks under dual task conditions, which suggests that some of the large deficits reported in the literature are not due to capacity interference, but are caused by structural factors, such as peripheral presentations.

In a second experiment, two-dimensional pursuit tracking was paired with a letter typing task in which letters appeared on the screen within the moving square of the tracking target symbol and had to be canceled by typing the correct letter code on a three-key keyboard. The difficulty of this task was varied by incrementing memory load (larger sets of letter codes) or increasing the difficulty of motor control (selection of more complex motor response patterns). The main findings of this experiment were:

1. In single task conditions, both difficulty manipulations yielded similar decrements in typing performance. Manipulation of memory load tended to cause larger decrements than motor control difficulty.

2. In dual task conditions, typing performance further deteriorated and decrements were monotonically related to task difficulty.

3. Difficulty of motor control interacted with the relative priority of the typing and tracking tasks while memory load produced a constant additive increment over levels of priorities.

These results confirm our previous argument that the locus of load in manual control tasks resides in the motor control requirements. The results also confirm the prediction that a multiple resource model in which difficulty manipulations tapping a common resource for concurrently performed tasks will interact with priorities, while manipulations tapping a resource relevant to one task only will result in additive effects. At present, we have several experiments underway that seek further clarification of the multiple resource notion and its practical implications for the description of time-sharing performance.

TRAINING PROCEDURES TO IMPROVE TIME-SHARING PERFORMANCE

While the study of general issues relevant to the modeling of time-sharing behavior is continued, our past year's and current research is marked by an increased involvement in questions related to training and development of time-sharing skills and the determinants of improvement in time-sharing performance. Is there a general time-sharing factor, whether inherent or acquired, with training? Are different strategies developed for the performance of tasks when performed singly or in time-sharing conditions? What are the consequences of training subjects in conditions in which intertask priorities vary dynamically? These are some of the questions addressed in our studies.

An experiment presently underway in our laboratory addresses the last of the above questions--training with variable priorities. Two types of training conditions are contrasted in this experiment. In one type, tasks are performed concurrently and no priorities are indicated, or equal priorities are emphasized and feedback indicators are displayed. In the second types, the relative emphasis on tasks is dynamically varied during training and subjects are required to allocate their resources in different proportions among the tasks. Training with fixed or unspecified priorities may encourage development of single optimal interweaving strategy or even integration of the tasks. Training with variable priorities disrupts integration but sensitizes subjects to the efficiency of resources and the consequences of their allocation in various proportions to the concurrently performed tasks. The effects of the two training schedules are investigated, employing pursuit tracking and the letter typing task described earlier. Partial analysis of the results show that the group trained with variable priorities demonstrated larger improvement and higher levels of final performance than all other groups. When transferred to a new condition in which priority instructions and feedback indicators were eliminated, the group trained under variable priorities was superior to the other in its ability to shift resources in order to protect constant performance levels under uninformed variations of task difficulty. The encouraging first results of these experiments are currently substantiated, and further experiments are being conducted.

ULTRADIAN RHYTHMS IN SUSTAINED ATTENTION TASKS

Short-term rhythmic fluctuations in alertness may be of special significance for the understanding of the behavior of subjects in sustained attention tasks. Oscillatory variations in the quality or speed of performance (sometimes referred to as lapses of attention) of radar observers, radio operators, air traffic controllers, drivers, pilots, etc., are frequently observed and most commonly treated as a random factor or considered to reflect noisy elements of the human processing system. It may be that the short-term variability in physiological activity and behavior can be linked together and shown to reveal regularity and organization.

Our research investigates the relationship between 90 minute rhythmic cycles of physiological processes and the performance of skilled psychomotor tasks. One of the interesting findings in this research is that the physiological cycle affects the accuracy of the movements, but does not affect their speed. Cyclical increases and decreases in the accuracy measure of motor movements were observed with a peak-to-peak interval of 100 minutes. Cycle deviation corresponded but was not synchronized with physiological processes. No such changes were observed in the speed of movements. Additional data are being collected for a wide battery of performance tasks. The discovery of ultradian cycles in performance may lead to many applications in industry.

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KC-135 AVIONICS MODERNIZATION PROGRAM

The goal of the program is to design a two-pilot crewstation for the 135 which would eliminate the navigator. A series of simulation studies are being conducted to identify the avionics and automation required to replace the navigator. During the studies, workload measurement is a critical problem. Workload in the existing KC-135 has been measured by recording the time spent on various cockpit tasks during operational flights by a battery of measures (i.e., performance, task loading, secondary task, and subjective ratings).

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PILOT WORKLOAD AND SCANNING BEHAVIOR

Pilot workload is composed of at least two components: the physical and the mental. Physical workload has been measured for years; however, the mental workload is more difficult to quantify. There is a possibility that eye scanning data can be used to quantify mental workload. Laboratory tests

have been conducted which have attempted to establish such a link between mental workload and eye scanning data. In the tests, mental activity was altered by utilizing controlled levels of an auditory side task. The purpose of this auditory task was to rob time from the primary flying task. As the difficulty of the auditory task increased, the pilot's scanning behavior was affected. The pilots stared at the primary instrument and looked at the peripheral instruments less. In addition, their scanning sequences were disrupted with the increases in auditory task difficulty. This staring and sequence disruption were more pronounced for the less skilled pilots. The performance on the flying task was poorer with increases in auditory task. The results of the laboratory tests suggest that it is desirable to use an auditory task to increase the overall mental workload high enough such that system performance is affected, reflecting differences in display quality or procedure effectiveness.

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TIME ESTIMATION AS A SECONDARY TASK

For the past four years different apsects of time estimation have been investigated with the goal of developing a series of easy to use flight-related indices of primary task load. To date, such variables as technique (counting, tapping, neither, etc.), method (verbal estimation, production), concurrent activity (tracking, monitoring, simulated aircraft and helicopter flight, etc.) and feedback (presence or absence, persistence) and the interactions among these factors have been studied by myself and a group of graduate students at Ames Research Center. The production method, particularly if subjects do not count and do not receive feedback, is the easiest to implement, although there are some methodological problems. Reports have been issued or are being written on the whole sequence of experiments. Few future experiments are planned except for full mission validation and cross-correlation with other measures of workload.

DEFINITION OF SUBJECTIVE EXPERIENCE OF WORKLOAD

In order to use subjective rating scales of workload, it is essential to determine:

1. What it is about an experience that produces the subjective experience called "workload" (e.g., doing more than one expected, fatigue, confusion, uncertainty, competition between tasks, etc.). Simply the task demands or resulting performance are not enough to explain the fluctuations in response and performance that are obtained with apparently similar tasks for the same subjects. It is often the circumstances under which the task requirements are met, the expectations, experiences, motivations, training level, etc., of the pilot, and other so-called intervening variables that

generate different ratings of subjective workload. Using a modification of the Sheridan/Tulsa moving boxes paradigm, in which the pilots will be required to perform a series of flight-related tasks reduced to the simplest possible elements presented with varying amounts of uncertainty, in various orders, under different circumstances in order to determine what aspects of the situation produce fluctuations in the subjective ratings of workload.

2. Determine how to retain the pilot's memory of his cognitive workload during a task, when querying him at the conclusion of the task with a subjective rating scale. It is clear that individuals' memory of how many decisions they made, how many times they monitored, perceived, calculated, estimated, projected, listened, etc., during an interval is very faulty and that the cognitive components of preceding activity are the least likely elements to be represented in a pointed and detailed assessment of workload made retrospectively. Full mission simulations are planned in which pilots of a single-engine aircraft simulator and a 747 simulator will be asked to give detailed evaluations of their cognitive processes during and after flights with different techniques, scales, and memory aides. The subjective rating scales that evolve from the two experimental approaches will be used by NASA and the FAA in their effort to evaluate the concept of providing pilots with a cockpit display of traffic control information (CDTI) and by other research programs at Ames.

SUMMARY OF WORKLOAD ASSESSMENT RESEARCH AT AMES RESEARCH CENTER

The workload assessment effort at Ames Research Center has been recently expanded and formalized into a separate program. The purpose of the program is to investigate, develop, validate, and standardize subjective and objective measures of pilot workload and performance in laboratory, simulation, and in-flight environments. In order to do this, we felt that the following questions should be addressed:

What role, if any, do fatigue and emotional stress play in the subjective experience of workload?

Does the term workload refer to the demands placed on an operator, the effort he expends trying to meet the demands, or his success in doing so?

Can pilots distinguish among different sources of workload, such as physical, perceptual, etc.?

What is it about the circumstances under which a task is performed that alters the subjective experience of workload?

How well can pilots produce reliable and valid subjective ratings of workload in retrospect?

The initial focus will be on the development of subjective rating scales, as these appear to have the widest application. A simple pilot opinion survey was recently conducted to obtain ratings of the total, perceptual, cognitive, and physical workload involved in general aviation flight. These ratings will be used to generate primary task situations with different levels and dimensions of workload to serve as a test bed for the workload assessment program. The validity of this aproach will be assessed with a series of simulation experiments in our GAT-I facility in November. The results of this study will be described at Human Factors. Additional laboratory research has been completed in which a series of subjective rating scales have been used in conjunction with part-task simulations focused on Cockpit Display of Traffic Information issues. Cooper-Harper type rating scales, the rating scale proposed by Airbus Industries, the Pilot Workload/Technical Effectiveness scale, and several sets of bipolar adjective scales were studied in this environment. The initial results of this work will be reported at IEEE in Atlanta later this month. Earlier laboratory research was completed in which simple manual control tasks were used to generate different levels of task demands. Fifteen bipolar adjective scales were used to evaluate the differential effects of task demands (amplitude or frequency of the forcing function to be tracked), pilot effort (RMS stick activity) and performance (RMS_e/RMS_i) on the experience of workload and related factors. The results of the first of two studies was presented by Kathy Bird at Annual Manual in June. Additional studies in this area are planned this winter in which cognitive and perceptual tasks will be used in place of the primary physical tracking task to obtain additional subjective ratings under different levels of task demands. Further simulations are also planned.

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PILOT MODEL BASED ANALYSIS OF HELICOPTER MISSIONS

An important problem in helicopter mission task analysis is the assessment or prediction of expected pilot-vehicle performance and associated pilot workload in accomplishing the mission objectives. However, existing methods for performance and workload evaluation and forecasting are highly empirical and lack a cohesive analytical structure or framework. In an effort to remedy this situation, the U.S. Army Aeromechanics Laboratory at NASA-Ames Research Center has initiated a joint long-term program committed to the development of an analytical technology base for improved pilot-vehicle performance and workload analyses.

Selection of an appropriate model structure for the human pilot is crucial to the success of any model-based analytical methodology. Pilot model formulation must be based upon a thorough understanding of the mission objectives and their impact (as perceived by the pilot) on the tasks that the pilot must perform during the contiguous flight segments. The model structure should incorporate the essential elements of the pilot's information acquisition/processing, decision making, and control behavior within a systematic analytical framework.

The process of flying consists of performing a hierarchy of tasks corresponding to increasing levels of cognitive involvement. As a minimum, piloting tasks may be classified into two hierarchical categories: (1) lower level autonomous information processing and control tasks, and (2) higher level decision making tasks.

A hierarchical model for the pilot based upon the two level task decomposition has been developed and exercised.

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SUBJECTIVE RATING OF TASK DIFFICULTY

This report describes work done by the Human Factors Laboratory under Navy Subcontract Number N00123-79-C-0159. The purpose of this work was to determine the reliability of several established rating scales in estimating cognitive workload. Results of this study indicate that ratings of task difficulty are significantly related to performance scores; and for task difficulty levels up to performance breakdown, ratio scale ratings are significantly more accurate relative to performance scores than are category scale ratings. Problems of implementing each type of scale are discussed. The use of such scales will allow for the cost-effective assessment of workload imposed upon operators of any man-machine system, with special suitability for the test and evaluation stages of the developing F-18 air system.

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HUMAN FACTORS IN DESIGN AND EVALUATION OF AVIATION MAPS

An extensive program of work on workload in reading maps is included in a recent AGARDograph reviewing all known human factors work relevant to aviation maps. Mental workload is considered in relation to human capabilities and limitations, particularly of cognitive processing, in relation to task descriptions, and in relation to methods of measurement and assessment of maps. There is not a separate section on mental workload as such but evidence on mental workload is related to the objective of designing effective aviation maps.

HUMAN FACTORS IN AIR TRAFFIC CONTROL

A continuing series of evaluations on proposed air traffic control systems and subsystems for regions of the United Kingdom is conducted which normally employs measures of mental workload, most commonly subjective ones. A paper on mental workload (in Moray, 1980) related to air traffic control sets out

the problems encountered in this research. Workload measurement in air traffic control is also covered in some of the papers, including my own, on air traffic control in the special issue of Human Factors in 1980 devoted to air traffic control. Measures of mental workload have generally proven unsatisfactory in practical air traffic control contexts. The main reasons seem to be the gulf between the theoretical interest in mental workload which is high, and the practical problem of mental workload which is not simply high but too high or too low, so that practical steps must be taken, in the form of system design changes, equipment changes, changes in instructions, changes in allocation of responsibilities, changes of facilities, or changes of training etc., to alter a workload level which is inappropriate and leading to inefficiency or other problems.

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TEST BATTERY

The purpose of this research project is to develop a test battery of psychological and physiological measures in order to evaluate both the level and type of workload found in a flight deck environment. As the measures are defined and evaluation methods developed, a series of part-task simulations will be conducted to determine the utility and sensitivity of the selected measures. Performance measures and time-line data will also be collected during the simulations to be correlated with the workload data. All data will be used in the development of a workload assessment computer model for preliminary design evaluation.

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STUDY OF A SIMPLE CRITICAL TASK FOR MEASURING EFFECTIVE PILOT DELAY TIME WHILE TRACKING
National Aeronautics and Space Administration, Contract NAS2-2288

A closed-loop compensatory tracking task was developed which yields a measure of the human operator's time delay characteristics while tracking, constrains his behavior to within very narrow limits, and provides a low-variability indicator of the operator's tracking ability. The task is called the "Critical Task" because the operator is required to stabilize an increasingly unstable controlled element up to the critical point of loss of control.

Study results showed that, when operating near criticality, the subject's behavior was adequately represented by recently developed human operator

describing function models and adaptation laws. Further, the extrapolation of describing function data to the critical level of instability showed that the operator consistently loses control at small, but finite, mean stability margins. The just-controllable first-order divergence was shown to be related dominantly to the operator's effective time delay, and secondarily to the nominal variations of his average tracking characteristics and to mid-frequency phase lags due to long period kinesthetic adaptation effects. It was also found that the human operator's characteristics do not change as the system input level is decreased; hence, the critical task yields a valid limit when excited solely by the operator's remnant. The effects on the operator of different control device types (force, spring, and free) were investigated and the differences in critical task scores related to the operator's describing function characteristics. Step reaction time data were compared with the continuous measures of effective time delay and the autopacer scores. A sample analysis to determine the number of autopace trials necessary to achieve a confident measure was made.

EXPLORATION OF CONNECTIONS BETWEEN PILOT OPINION RATINGS,
PILOT DYNAMICS, AND SYSTEMS CHARACTERISTICS
Air Force Flight Dynamics Laboratory, Contract AF 33(615)-3960

The purpose of this study was to determine the correlation between pilot and system dynamics on opinion ratings and to evolve a valid opinion scale lacking the deficiencies of past scales. To establish the effects of pilot and system dynamics and performance on opinion, recent data gathered under Air Force Contract AF 33(657)-10835, "Human Pilot Dynamics in Compensatory Systems," was used. The results of that study, which determine the operator's characteristics and behavior with dynamics representative of a number of idealized flight control situations, were correlated with existing opinion rating data. Thus, the effects of pilot gain, reaction time delay, equalization, and neuromuscular system characteristics on opinion were determined. At the same time a refined opinion scale (or scales) were evolved through a careful assessment of both objective and subjective pilot and system characteristics.

Although rating scales of varied forms have been widely used to estimate and evaluate handling qualities over the past decade, a number of deficiencies in both method and data base have been apparent. This investigation was aimed at overcoming many of these deficiencies by attempting to resolve the difficulties experienced with rating scales themselves and by extending and adding to already existing relationships between ratings and pilot/vehicle system parameters.

Rating scales have come under increasing criticism for problems related to wording ambiguity, the dual mission character of some scales, the nonuniformity in the distribution of descriptors across the scale, and the misuse of scales which has occurred when ratings have been averaged. Psychometric methods provide an approach to these problems and in this study were used to scale several phrases descriptive of vehicle handling qualities. Thus, quantitative characteristics were derived from contemporary scales through the use of a scaling technique known as the "Method of Successive Intervals," where data for the method were obtained from a survey experiment.

An experiment was conducted which added to available data relating Cooper ratings and pilot/vehicle parameters, and which also tested some potential alternate scale candidates. The correlation results indicate that ratings are probably based on performance and the degree of difficulty experienced in maintaining the performance. The difficulty is most easily represented by the pilot equalization required and the vehicle stick characteristics.

EXPERIMENTS FOR A THEORY OF MANUAL CONTROL DISPLAYS
National Aeronautics and Space Administration, Contract NAS2-3746

This research effort spanned several years and involved a long-range program to develop a comprehensive theory for understanding, analyzing, and improving the pilot's use of manual control displays. One facet of the program was to evolve efficient and analytical models for the pilot's tracking of quasi-predictable forcing functions (e.g., following the optical landing beam of an aircraft carrier plunging through deep ocean swells, terrain-following flight over rolling countryside, etc.). As a part of the experimental program, a novel technique was used to force the subjects (skilled instrument-rated pilots) to scan two displays in a manner that is realistic yet controllable by the experimenter. This was done via a "subcritical" side task (stabilizing a slightly unstable first-order plant), such that the time away from the side task (i.e., available for the main task) is limited by the time-constant of the divergence. In order to preclude parafoveal cues, eye-movement signals were used to blank the nonfixated display in certain cases and some performance decrements were found. It was found that the pilot's average scanning, sampling, and reconstruction behavior can be accurately modeled by an adjustable quasi-linear describing function, plus an injected "scanning remnant" (observation noise) having wideband properties.

The model was validated by a series of experimental measurements of pilot scanning and control response in a simulated instrument approach. Seven subjects flew Category II-like ILS approaches in a six-degree-of-freedom fixed-base DC-8 simulator at the NASA Ames Research Center. A conventional instrument panel and controls were used, with simulated vertical gust and glide slope beam bend forcing functions. Pilot eye fixations and scan traffic on the panel were measured using a recently-developed eye-point-of-regard (EPR) system. The EPR data were reduced for 31 approaches with a cross-section of subjects to obtain dwell times, look rates, scan rates, and fractional scanning workload. Simultaneous recordings were made of displayed signals, pilot response, and vehicle motions to permit their correlation with the eye movement results.

RESEARCH ON A NEW HUMAN DYNAMIC RESPONSE TEST BATTERY
National Aeronautics and Space Administration, Contract NAS2-4405

A battery of autopaced critical-instability tasks, subcritical tracking tasks, and step reaction-time tests was developed to permit efficient measurement of the limiting human dynamic response properties. Standard test parameters for first-, second-, and third-order controlled elements (the latter requiring double-lead equalization) were given. Comprehensive "baseline" measurements were made on four well trained subjects (three were

pilots) using a specially-built Controlled Element Computer and an on-line Describing Function Analyzer. The resulting data included: tracking errors, describing functions (and derived loop closure and model-fitting parameters), remnant, critical instabilities, and reaction times. A number of simultaneous psychophysiological measurements were also made. These included electrocardiogram, "instantaneous" heart rate, breath flow, electromyograms, average grip pressure, and palmar skin resistance.

These data showed consistent increases in the neuromuscular tension indicators during tracking. Breathing was usually faster and shallower. The average heart rate increased for only two of the four subjects but distinct increases in the cardiac "sinus arrhythmia" were noted, which were completely correlated with breath flow. Remarkably simple correlations were obtained between the critical instability and various other closed-loop dynamic performance metrics. These tests and results constitute the foundation for a series of continuing experiments on effects of environmental stresses and workload.

Also as a part of this program, STI administered a tracking tasks battery during a 90-day confinement experiment to determine the physiological and psychological effects of long duration confinement in a space station atmosphere. The battery included a "clinical" test (Critical Instability Task) designed to measure a subject's dynamic time delay and a conventional steady tracking task, during which dynamic response (describing functions) and performance measures were obtained. The subjects were extensively trained prior to confinement and generally reached asymptotic performance levels.

Good correlation was noted between the clinical critical instability scores and more detailed tracking parameters such as dynamic time delay and gain-crossover frequency. The levels of each parameter spans the range observed with professional pilots and astronaut candidates tested previously. The chamber environment caused no significant decrement on the average crewman's dynamic response behavior and the subjects continued to improve slightly in their tracking skills during the 90-day confinement period. Some individual performance variations appeared to coincide with moral assessments made by other investigators. The comprehensive data base on human operator tracking behavior obtained in this study demonstrates that sophisticated visual-motor response properties can be efficiently and reliably measured over extended periods of time.

RESEARCH ON THE EFFECT OF DISPLAY PARAMETERS
ON HUMAN CONTROLLER REMNANT
Air Force Flight Dynamics Laboratory, Contract F33615-69-C-1808

This study was a first step toward the long-range goal: to develop efficient analytical models for human controller remnant which were as useful as current quasi-linear pilot models in manual control/display systems design. This contract concentrated on selected single-loop display situations in which remnant is predicted to be appreciable. First, using new theoretical guidelines, an extensive archive of remnant data at STI was reanalyzed to provide a data base for refining the remnant models. Then, a series of brief experiments were performed, using remnant-sensitive displays

such as quantized bar graphs, moving-tape scales, and parafoveal displays. These experiments made use of the STI-developed Controlled Element Computer and on-line Describing Function Analyzer. In addition to describing functions and remnant spectra, subjective workload ratings and (where relevant) scanning workload were measured.

FLIGHT EXPERIMENT AND FLIGHT HARDWARE SPECIFICATION DEFINITION
National Aeronautics and Space Administration, Contract NAS2-6409

Contract NAS2-4405 brought the development of the Critical Tasks Battery to a fruitful stage of application for laboratory research. The Mark II CTB has been used in the NASA-McDonnell Douglas 90-Day Confinement Experiment and has been proposed for use under vibration stress and g-stress. An orbital version of this test apparatus has been proposed for a space experiment on human operator dynamics under orbital conditions. This contract involves completing the preliminary research and design, as required to proceed rapidly with the orbital hardware fabrication, should the proposed orbital experiment be approved. Flight experiments and hardware specification definitions include hybrid analog digital CTB mechanization, finalization of multiaxis workload test, and design specifications for orbital tester hardware.

The various tests in the battery were applied to a set of simulated Space Shuttle reentry experiments utilizing the Ames Research Center centrifuge. Effects of cardiovascular deconditioning were investigated via several days of bedrest.

ENGINEERING PSYCHOLOGY RESEARCH SERVICES
National Aeronautics and Space Administration, Order No. A-29602B

This program was part of an Army project, funded through NASA, to establish and develop new methods to measure, quantify, and predict helicopter aircrew workload. The effort provided background information to guide the selection of R&D strategy for development and verification of this new methodology. It was coordinated with other contract and in-house technology assessments of workload measurement research using several basically different approaches. This part of the project concentrated on procedures which assess primary task performance in some manner as the basic element of a workload measurement procedure. To accomplish the objectives of this program, a comprehensive survey of the aerospace human engineering, behavioral sciences, flight simulation, and vehicle control literature was made to identify and review all such primary task measurement methods for vehicle operator workload appraisal.

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MENTAL WORKLOAD IN A SIMULATED DRIVING TASK

Tracking is one important component in car driving. That is why it is used as a paradigm in an experiment to test different variables as workload indicators. The difficulty of the main task is changed in three levels by varying the frequency of the forcing function of a velocity system with the one-dimensional tracking task. Workload indicators are:

1. A unipolar graphic rating scale.

2. A secondary task where a pointer moves on a horizontal scale; the subject has to press a knob when the pointer enters a warning zone of the left and right end of the scale.

3. Different measures of heart rate and heart rate varability (time domain and frequency domain measures).

4. Primary task measures like steering reversals, steering activity.

The feasibility of these indicators is examined in terms of reliability, validity, and freedom of interference. Results show that the most valid workload indicators are the rating scale and the secondary task. Nevertheless, all of them have severe limitations. In subsequent investigations, the same workload indicators will be measured in experiments with a car driving simulator.

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TIME-SHARING AND MENTAL WORKLOAD

Current research attempts to expand the hybrid model of dual-task performance proposed by Kantowitz and Knight (1976). Payoff matrices are used to sweep out performance operating characteristic functions. Results are consistent with the hybrid model but do not rule out alternative models of time-sharing.

ENVIRONMENTAL STRESS AND MENTAL WORKLOAD

This research uses our new environmental chamber to investigate double-stimulation tasks performed at varying temperatures and humidities. The

first experiments are scheduled for Fall 1981 and will examine narrowing of attention in a psychological refractory period paradigm.

RESPONSE TOPOGRAPHY AND MENTAL WORKLOAD

Most research with a discrete secondary task has used reaction time and error rates as dependent variables. Since response topography is a more fundamental aspect of behavior than is RT, this research records the analog force emitted by subjects making controlled motor outputs on isometric force transducers. The initial experiments will provide single-stimulation baseline data. Later experiments will evaluate mental workload in two-handed movements and in time-sharing paradigms.

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PROJECTED WORKLOAD

The workload literature ordinarily studies the effects of load by a metric that deals with the amount of information that is presented/processed per unit of time over available pathways. In this way, functional reserve can be assessed. It is my intention to expand on the temporal demands of workload (presently limited to studies of keeping track, historically, of several things at once with changing status) by measuring how far into the future the controller of a sy cem can predict. It is expected that functional reserve, so measured, will improve with practice.

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NADC PROGRAMS

NAVAIRDEVCEN has two major programs ongoing at the center. In addition, it supports and sponsors work at other government centers, particularly that at the Naval Air Test Center (Sam Schiflett). The latter is separately documented by Dr. Schiflett. Current NADC programs are focused principally on workload and performance estimation models. These include the Workload Assessment Model (WAM) of the CAFES system and the Human Operator Simulator (HOS) model.

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SECONDARY TASK REVIEW

The post-1965 literature on the use of secondary tasks in the assessment of operator workload was surveyed. Twelve classes of tasks were identified; the most frequently used were choice reaction time, memory, monitoring, and tracking. The literature review did not suggest a single best task or class of tasks for the measurement of workload. Limitations in using secondary tasks are discussed, and directions for future research are presented.

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A MODEL-BASED TECHNIQUE FOR PREDICTING PILOT OPINION RATINGS

A model-based technique for predicting pilot opinion ratings has been developed and tested. Features of this procedure, which is based on the optimal-control model for pilot/vehicle systems, include (1) capability to treat "unconventional" aircraft dynamics, (2) a relatively free-form pilot model, (3) a simple scalar metric for attentional workload, and (4) a straightforward manner of proceeding from descriptions of the flight task environment and requirements to a prediction of pilot opinion rating. The method is able to provide a good match to a set of pilot opinion ratings obtained in a simulation study of large commercial aircraft in landing approach.

MODELS FOR CREW PERFORMANCE

We are developing analytic models to examine crew performance and workload in multi-task environments, involving both continuous and discrete tasks. The models will permit investigation of the effects of a number of tasks to be performed, selective attention to tasks, and task completion times. Multioperator situations involving intra- and extra-crew communication are also being studied so that the effects of such communication, as well as the distribution of tasks, on predicted crew workload can be examined. The initial and preliminary applications of these models has been to control the analysis of the remotely piloted vehicles and to flight crew procedures in approach and landing.

USER'S GUIDE TO THE TRACKING TASK

A manual will be written to guide the user in the effective use of the continuous tracking task and in the interpretation of tracking performance measures as they apply to studies of mental workload.

ANALYTICAL AND SIMULATOR STUDY OF ADVANCED TRANSPORT HANDLING QUALITIES

An analytic methodology, based on the optimal-control pilot model, is demonstrated for assessing longitudinal-axis handling qualities of transport aircraft in final approach. Calibration of the methodology is largely in terms of closed-loop performance requirements, rather than specific vehicle response characteristics, and is based on a combination of published criteria, pilot preferences, physical limitations, and engineering judgment. Six longitudinal-axis approach configurations were studied covering a range of handling qualities problems, including the presence of flexible aircraft modes. The analytical procedure was used to obtain predictions of (1) Cooper-Harper ratings, (2) a scalar quadratic performance index, and (3) rms excursions of important system variables. A subsequent manned simulation study yielded objective and subjective performance measures that varied across vehicle configurations in the manner predicted by model analysis.

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TASK

Pilots at various levels of experience will fly simulated hostile threat missions in the A-10 or F-16 versions of the ASPT (Advanced Simulator for Pilot Training).

1. Description of Typical Mission. Pilot is released in a safe zone which is approximately 4 minutes' flying time from the hostile zone. Pilot flies into hostile zone and completes a mission (e.g., destroying a tank or other object by cannon fire. Pilot will be in the hostile zone approximately 10 minutes and will be fired upon by AA or ground-to-air missiles. Pilot then leaves hostile zone and flies in safe zone for about 4 minutes. Total mission time is about 18 minutes; and during this time, the pilot will be presented with tones over his headset every five seconds. There are three tones which differ in frequency and which communicate specific information to the pilot as follows: 1000 Hz tone signals NO THREAT, a 1500 Hz tone signals MEDIUM THREAT (being tracked by radar but not yet fired upon), and 2000 Hz tone signals

HIGH THREAT (a device has been launched against your aircraft). The information provided by the tones will always be veridical; no deception is involved. To maintain realism for the pilot, the number of MEDIUM THREAT and HIGH THREAT tones will be varied on different missions.

2. Each pilot will fly multiple missions interspersed with short breaks.

3. The purpose of the tones is to elicit event-related potentials from a vertex to right mastoid derivation. Preliminary work will be conducted at ASU to insure that the different tone frequencies do not produce different ERPs because of the particular frequencies used, rather than the meaning attached to them. It is unlikely that the small range of frequencies used will elicit different ERPs due to frequency of tone. However, it is fully expected that the ERPs to HIGH THREAT, MEDIUM THREAT, and LOW THREAT tones will differ reliably due to the information value of the tones.

DEPENDENT VARIABLES

ASPT computes several indices of mission performance. The primary thrust of the present research is to relate physiological indices of mental workload to ASPT performance variables. The physiological variables of greatest initial interest are heart rate, pulse transit time, ERP, and eye movement (EOG). The latter is used largely as a control for the ERP since large eye excursions can contaminate the brain wave recording. Other possibly relevant measures are skin conductance, respiration rate, and body temperature. Exactly which set of physiological variables are best indicators of workload is not known at the present time; indeed, one goal of the project is to screen different measures for usefulness.

SPECIAL HARDWARE

Custom designed 6-channel biotelemetry systems are currently being manufactured by UFI, Morro Bay, California, to support this research.

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NADC PROGRAMS

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INDIVIDUAL DIFFERENCES IN TIME-SHARING WITHIN THE FRAMEWORK OF A STRUCTURE-SPECIFIC RESOURCES MODEL OF HUMAN INFORMATION PROCESSING

The objectives of the research are:

1. Develop a paper and pencil instrument to assess certain verbal and spatial abilities, and cognitive styles (e.g., field independence) which are considered important in flying.

2. Develop a psychomotor test battery which will test skills specifically related to operational flying and investigate time-sharing skills within the framework of a structure-specific capacity theory of attention.

3. Determine if individuals maintain a consistent relative hierarchy among the structures across different time-sharing situations.

4. Investigate the relationship between specific cognitive abilities and time-sharing mechanisms.

5. Determine which time-sharing performance (i.e., time-sharing within or between the various structures) is the best predictor of complex flight performance in a simulator.

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THE RELATION BETWEEN HUMAN PERFORMANCE AND BIOMEDICAL INDICES IN EVALUATIONS OF POTENTIALLY ADVERSE FACTORS IN THE AVIATION ENVIRONMENT

The purpose of this project is to define the biomedical and performance implications of the kinds of stresses imposed on aviation personnel (e.g., altitude, fatigue, sleep loss, drugs, alcohol, dieting, and medical conditions). This task of the CAMI Aviation Psychology Laboratory (AM-A-81-PSY-85) provides performance measurement support to the Aviation Physiology Laboratory's task AM-A-81-PHY-133. The CAMI computerized Multiple Task Performance Battery (MTPB) is used to assess complex (time-sharing) performance in a synthetic work situation involving the monitoring of light signals and meters, processing of arithmetical information, problem solving, visual pattern discrimination, and perceptual-motor control (two-dimensional compensatory tracking). Five subjects can be run simultaneously in this apparatus. Different combinations of tasks are programmed to vary workload. Subjects are typically given 12 hours of practice on the MTPB before experimental testing is begun. Data analyses are based on time and accuracy measures. In addition, a composite index can be computed to reflect the overall quality of performance. Relations between performance and biomedical measures obtained in corollary studies by the Aviation Physiology Laboratory receive special emphasis.

RECENT RESEARCH

Crash Diet Experiment. FAA statistics reveal that the weight of the average civilian airman is 22.7 pounds above the average acceptable weight according to weight/height guidelines, and that the prevalence of obesity is increasing in this group. An experiment was conducted to evaluate the effect on complex performance of one of the more stringent dieting strategies, the crash diet, which involves abstinence from caloric intake for at least 24 hours. Performance testing with the MTPB followed both a 24-hour crash diet and a 24-hour normal diet. During performance testing, 12 male subjects breathed an O_2/N_2 gas mixture equivalent to 12,500 feet, the highest altitude at which continuous flight is permitted without supplementary oxygen. There were no significant effects of crash diet under low workload. Several measurements showed a slight enhancement of performance by crash diet under medium and high workload conditions. Physiological measurements indicated an energy conservation pattern (reduced activity) during the crash diet condition. Although no adverse effects of the crash diet were observed, the possibility should be considered that longer periods of dieting or interactions of mental and physical fatigue with dieting could lead to performance deficit.

Smoking Withdrawal Experiment. A petition to the FAA to prohibit smoking on the flight deck of air carrier aircraft led to an experiment which evaluated

the effects of short-term smoking withdrawal on the complex performance of habitual smokers. Seventeen men and women who were habitual smokers performed on the MTPB in two 4-hour intervals in the other session. During testing subjects breathed an O_2/N_2 gas mixture equivalent to a cabin altitude of 6,500 feet, a common cabin altitude in pressurized air carrier aircraft. When smoking was prohibited, MTPB performance decreased significantly, largely as a function of decrements in tracking. Higher heart rates and higher ratings of attentiveness occurred during the smoking condition and are consistent with the performance data. A cautious approach to the prohibition of smoking during flight by air crewmembers is suggested. Milder approaches such as smoking cessation programs were recommended. Future research in this area should concern the effects of longer periods of withdrawal and higher cabin altitudes.

CURRENT RESEARCH

In the current year, data collection has been completed in an experiment concerning the effects on complex performance of the interaction of physical fatigue and altitude. Performance testing occurred in ground level and altitude (12,500 feet) conditions during a 3.5 hour recovery period following strenuous exercise and control treatments. Data analysis is in progress. Data collection is proceeding in a study of the interaction of alcohol effects with altitude. Subsequent experiments will concern the effects of mental fatigue as a function of age and the effect of hangover and altitude on complex performance.

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RECENT EFFORTS IN PLANNING AND DEVELOPING HELICOPTER WORKLOAD METHODOLOGY AND ASSESSMENT

Methodology has been planned and developed for conducting and assessing crew workload (timelines) and crew coordination (visionics symbology and voice communications) during dedicated two-manned flight operations testing. Parameters have been described for on-ground and airborne collection of quantitative data on PCM data watanabe stripcharts and MUX data strip plots. Measurement instruments to convert crew attitudes on crew workload and crew coordination to numerical values by scaling techniques have also been investigated.

FUTURE EFFORTS IN APPLYING HELICOPTER MENTAL WORKLOAD METHODOLOGY AND ASSESSMENT

Activities in helicopter workload methodology and assessment for perceptual, meditational, communication, and motor processes are being proposed for the near future.

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FIGHTER CONTROLLER BEHAVIOR

A project funded by M.O.D. U.K. to measure and model the attention behavior of radar operators. Eye movements are measured in simulators and live sorties. A computer model of the behavior is being developed based on a "diffusion" theory of forgetting, and on Markov analysis. Patterns of differential attention given to different aspects of the display are emerging. The role of memory is particularly emphasized.

CORRELATION OF BEHAVIORAL, PHYSIOLOGICAL, AND SUBJECTIVE WORKLOAD MEASURES

An experiment is planned for Autumn 1980 using three bandwidths of Gaussian noise, three orders of control, heart rate, and GSR measures (with special interest in the 0.1 Hz component of heart rate, and subjective scaling of difficulty.)

DEVELOPMENT OF A GENERAL THEORY OF HUMAN INFORMATION PROCESSING AND WORKLOAD

This uses the speed/accuracy tradeoff as a central theme and concentrates on sampling models of attention such as Sheridan's Supervisor Theory and Senders' Queuing Theory, plus sequential decision making and exponentially weighted forgetting of past observations.

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PERFORMANCE RESEARCH

Our research has not been directly concerned with the assessment of workload or the effects of workload. Rather, the primary thrust of our research has been conducted with the assessment of performance effects of stressful conditions. In this research, we have several levels of workload to produce realistic performance requirements in a synthetic work situation, and to determine the effects of various stresses on performance at the different workload levels. One of the consistent findings has been that the effects of stress on team performance is directly related to the task which the team is performing.

EFFECTS OF TRAINING CONCURRENT-TASK STRATEGIES ON THE ACQUISITION AND TRANSFER OF COMPLEX SKILLS

This study investigates the acquisition and transfer of concurrent-task skills of different workload requirements through the use of differential training regimens designed to influence what strategies learners adopt. The purposes of the study are to determine the effects on enhancing dual-task acquisition and transfer to a multiple-task criterion of (1) differential training conditions; (2) changes in training; and (3) interactions between different concurrent-task combinations and different training regimens. The design of the study is a six-group split-plot with two phases of training.

During the first phase of training, 60 subjects, in groups of five, will practice mental arithmetic, vigilance, and a group procedural task under single-task conditions or changing priority concurrent-task conditions. For the concurrent-task practice groups, each of the three tasks will be combined with each of the other two tasks. The practice session will be followed by a multiple-task transfer session composed of a schedule of rapidly changing task combinations and demands. During the second phase of training, a part of the subjects will be shifted to a new regimen for dual-task practice, followed by a second transfer session.

The data from the training and transfer sessions will be analyzed by means of mixed factorial analyses of variance. Both rate of acquisition and asymptotic performance will be tested. It is hypothesized that type of training will have differential effects on acquisition and transfer of concurrent-task skills. Attention will be given to the differential effects of type of training for tasks that represent different workloads.

INDIVIDUAL DIFFERENCES IN MULTIPLE-TASK PERFORMANCES

Several recent efforts have provided data that contribute to the understanding of individual differences in multiple-task performances involving different workload levels. Data from a previous investigation of the effects of continuous work and sleep loss on subject's performance on the Multiple-Task Performance Battery (MTPB) of the synthetic-work methodology have been reanalyzed so as to examine (1) the range and consistency of individual differences at different workload levels, (2) individual differences in the acquisition of skill in performing tasks representing different workload levels, and (3) the predictability of individual performance at different workload levels during continuous work and sleep loss. Results of these analyses indicate that there are very large individual differences in response to stress at all workload levels. It was also found that regardless of workload level during MTPB performance, individual subjects were quite consistent in their response to four exposures to continuous-work and sleep-loss stress; that is, all measures of performance indicated that poor (or good) performance under the first stress exposure were also poor (or good) performances under the other three exposures. These consistent individual differences also seem to be predictable from individual performances just prior to the stress exposures (correlations across the four exposures and the individual performance measures ranged from .57 to .99). Other

analyses have indicated that within the synthetic-work, multiple-task situation, different subjects learn a given task at different rates. Furthermore, for a given individual, the rates of skill acquisition are different for different MTPB tasks; further study is needed in order to determine the extent to which these differences are due to difference in workload produced by the different tasks. Recent analyses indicate that rates of acquisition of performance on the least-difficult tasks (watchkeeping) were positively correlated with performance during stress, whereas rates of skill acquisition on the most difficult task (math) were negatively correlated with performance under stress. Additional research is needed to explicate relationship between workload effects and the potential utility of skill-acquisition rates as predictors of performance under stress and in other operational situations.

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PROJECT 1, RESOURCE SPECIFICITY OF COMPONENTS OF CORTICAL EVOKED POTENTIALS (1980-1983)

In recent theories of mental workload, it is assumed that human workload is a multidimensional construct; that is, the workload of a task is not a scalar quantity but a vector quantity associated with some number of yet to be identified dimensions (e.g., Derrick, 1981). Recent research suggests that components in event-related brain potentials can be used in the assessment of allocation of attention (e.g., Wickens, Heffley, Kramer, Donchin, 1980).

Especially the P_{300} has been proposed as an index of perceptual load on perceptual resources.

The aim of our project is to determine the sensitivity of endogeneous negative and positive components to task variables affecting perceptual, central, and motor mechanism. The following task variables are used:

1. Display Load
2. Memory Load
3. Combinations of Display and Memory Load
4. Stimulus Degradation
5. Training in Consistent versus Varied Mapping Conditions
6. Response Probability
7. Stimulus Response Compatibility

Task variables 1 and 2 are also examined during speed and accuracy regimes.

A computer-algorithm has been written which identifies specific components in single trials.

PRELIMINARY RESULTS

An early negative component (N_{175}) is very sensitive to display load but not to memory load. A late positive component (P_{550}) is very sensitive to both memory and display load. Sensitivity is visible both in changes in latency of amplitude of these components. Response probability also affects the P_{550} component, but not stimulus response compatibility.

PROJECT 2, TASK RELATED CARDIOVASCULAR STRESS

This project studies the sensitivity of cardiovascular indices to the processing demands of mental tasks. The main dependent variables are power spectrum analysis of heart rate and blood pressure fluctuations, the preejection period, left ventricular ejection time and pulse transmission time. Discrete mental tasks are used, ranging from search tasks to sentence comprehension tasks to language translation tasks (simultaneous interpretation).

Results indicate that the 0.10 Hz component of the cardiac interval signal, a component related to the frequency response of the baroreceptor reflex, is diminished during tasks which require controlled processing and in which respiratory activity is regular, and increased during tasks which require controlled language processing. In both cases the homeostatic mechanisms of short-term blood pressure control are highly changed; in the first case there is a diminished baroreceptor sensitivity; in the latter case baroreceptor sensitivity is increased. These data, together with other indices, indicate the existence of different required cardiovascular states. Individual profiles indicating reactivity are used as a first step in identifying individuals at risk.

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WORKLOAD AS A FACTOR IN AIR CARRIER INCIDENTS
THAT EXEMPLIFY DEFICIENT RESOURCE MANAGEMENT

A set of 250 commercial aviation incidents exemplifying deficient team functioning in the utilization of available resources was selected from the 7,689 incidents reported to the NASA Aviation Safety Reporting System during the period from 15 April 1976 to 23 May 1978. Each incident was rated as to the extent selection criteria were met. The 84 highest rated exemplars were designated for more comprehensive analysis. Resource management was formally defined as a man-machine system concept. A definition-related schema

for incident analysis was developed in which workload was one of the possible categories to which evolutionary and recovery factors were classified. Workload, here used to categorize factors involving problematic input load, enabled or contributed to the evolution of 25 of the 84 incidents. In many of these incidents deficient workload management, involving an inadequate setting of task priorities, was more proximally related to incident evolvement. Details of this study are documented in "Analysis of Eight-Four Commercial Aviation Incidents: Implications for a Resource Management Approach to Crew Training," by M. R. Murphy, in the Proceedings of the 1980 Annual Reliability and Maintainability Symposium, 22-24 January 1980, San Francisco, California. This analytic effort is being extended in depth and to include additional incidents.

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TASK LOAD AND OPERATOR ATTENTION CAPACITY
IN TIME-SHARING PERFORMANCE

The goals of this investigation are to provide conceptual framework, develop methodologies, and propose measurement procedures to assess task load and operator attention capacity in the performance of complex tasks.

Consistent with these objectives, a new approach to human performance under time-sharing conditions has been proposed and initially tested. This approach is based on economic concepts and used to derive predictions and discuss possible sources of interference in concurrent performance. Some prevailing concepts such as "difficulty," "resources," "load," and "efficiency" have been formally examined and redefined and new distinctions have been proposed.

To get a complete picture of performance limitations under time-sharing conditions, it is proposed to manipulate task preference as well as difficulty parameters and present their joint effects by families of trade-off functions. This approach was applied to explore the interactions between axes in two dimensional tracking tasks. Additional experiments along these lines are currently being conducted on pairs of tracking and digit classification tasks and angular tracking paired with position tracking.

Two directions of future research are proposed: one represents a continued thrust to identify the nature and sources of limitations of the human processing system. It is accompanied by an effort to develop measures of workload under time-sharing conditions. A second line of studies is proposed to investigate the implications of this research for the development of training procedure and learning processes in the acquisition of time-sharing skills.

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A methodological approach to measuring workload was investigated for evaluation of new concepts in VTOL aircraft displays. Physiological, visual response, and conventional flight performance measures were recorded for landing approaches performed in the NASA Langley Visual Motion Simulator (VMS). Three displays (two computer graphic and a conventional flight director), three crosswind amplitudes, and two motion base conditions (fixed versus moving base) were tested in a factorial design.

Multivariate discriminant functions were formed from flight performance and/or visual response variables to maximize detection of experimental differences. The flight performance variable discriminant showed maximum differentiation between crosswind conditions. The visual response measure discriminant maximized differences between fixed versus motion base conditions and experimental displays.

Physiological variables were used to attempt to predict the discriminant function values for each subject/condition trail. The weights of the physiological variables in these equations showed agreement with previous studies. High muscle tension, light but irregular breathing patterns, and higher heart rate with low amplitude all produced higher scores on this scale and, thus, represented higher workload levels.

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AFAMRL WORKLOAD ASSESSMENT PROGRAM

The USAF is vitally interested in developing and implementing techniques for assessing the workload imposed by existing and future systems. A major effort is being carried out by the Aerospace Medical Division, Air Force Aerospace Medical Research Laboratory, to develop, validate, implement, and standardize techniques for assessing such workload. The program is broadly based to include subjective measures, behavioral/performance measures, and neuropsychological/physiological measures. Specific experiments are being carried out by a number of individual principal investigators to identify new approaches to measurement, test technological approaches in laboratory and field settings, and optimize assessment techniques with respect to validity and sensitivity. The entire effort is designed to yield usable standards which can be applied to systems workload evaluation at any stage of design. Such standards are projected as Air Force specifications in CY85. In addition, several generations of workload test batteries and computer models will be produced. For specific efforts under this program, see Shingledecker, Eggemeier, Wilson, Reid, and Crabtree entries.

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MENTAL WORKLOAD IN A SIMULATED DRIVING TASK

Tracking is one important component in car driving. That is why it is used as a paradigm in an experiment to test different variables as workload indicators. The difficulty of the main task is changed in three levels by varying the frequency of the forcing function of a velocity system with the one-dimensional tracking task. Workload indicators are:

1. A unipolar graphic rating scale.

2. A secondary task where a pointer moves on a horizontal scale; the subject has to press a knob when the pointer enters a warning zone of the left and right end of the scale.

3. Different measures of heart rate and heart rate varability (time domain and frequency domain measures).

4. Primary task measures like steering reversals, steering activity.

The feasibility of these indicators is examined in terms of reliability, validity, and freedom of interference. Results show that the most valid workload indicators are the rating scale and the secondary task. Nevertheless, all of them have severe limitations. In subsequent investigations, the same workload indicators will be measured in experiments with a car driving simulator.

DESCRIPTION OF WORK IN PROGRESS

In our last experiments, different workload measures were tried out. So, a graphic rating scale, a secondary task (monitoring and decision making), mean cardiac interval time, and four measures of heart rate variability were used to assess mental workload in a simulated car driving task and were compared on the basis of reliability and validity. The difficulty of the car driving task was varied in three levels by changing the cut-off frequency of the forcing function.

Tracking error in the simulated car driving task significantly increased with higher difficulty levels. Graphic rating scale scores also increased significantly with primary task difficulty levels, indicating that it is a valid method for measuring workload. Internal consistency of the rating scale proved to be satisfactory as well.

Secondary task error as a measure had a retest reliability good for group comparisons but not for individual comparisons. Its validity as a workload

indicator was lower than that of the rating scale. Of all workload assessment procedures used, cardiac measures had the highest retest reliabilities (with the exception of one variable). However, the validity of the cardiac variables as workload indicators was low. Only one measure of heart rate variability differentiated approximately as well as the secondary task's scores.

Now we are planning new experiments where we use a secondary task based on psychophysical methods.

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TEST BATTERY

The purpose of this research project is to develop a test battery of psychological and physiological measures in order to evaluate both the level and type of workload found in a flight deck environment. As the measures are defined and evaluation methods developed, a series of part-task simulations will be conducted to determine the utility and sensitivity of the selected measures. Performance measures and time-line data will also be collected during the simulations to be correlated with the workload data. All data will be used in the development of a workload assessment computer model for preliminary design evaluation.

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PERFORMANCE EVALUATION IN TRAINING SIMULATORS

The purpose of the project is to develop a method for observation and analyses of operator performance, which can provide data on decision making in critical situations. One condition is that the observations must not disturb the normal use of the training simulator, or interfere with the instructor's normal work. This will make it possible to collect data from a large number of highly realistic situations with stress and high mental workload. The observations are based on a detailed description of the expected performance, which is used to detect discrepancies (faults and mistakes in the performance). The analysis is based on the general decision model and performance analysis principles developed at RISO and used in a considerable number of international projects. The results from the pilot test support the usefulness of the approach.

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SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)

There are a number of reasons, both theoretical and practical, why any complete workload test battery should include a subjective measurement technique. Also, a need exists for a subjective measure that has been systematically developed and evaluated so that it can be generally applied in various situations. SWAT is being developed as a candidate generalized measure. SWAT is based upon a conceptualization of workload as a multidimensional concept. Three dimensions (time load, mental effort, and psychological stress) are defined. Conjoint measurement is used to define the combination rule used by subjects in ordering descriptors for all possible combinations of levels of the three factors. Conjoint scaling is then used to establish a scale which conforms to the combination rule and maintains the ordinal structure of the original data. The result of this procedure is an interval level workload scale for application to specific events of interest to an investigator.

SWAT-1, a three-level version, is available. Data demonstrating validity and reliability have been obtained. SWAT-2, a five-level version, is being developed to provide a scale with finer discriminations.

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EFFECTS OF NEW TECHNOLOGIES IN OFFICE WORK

THESIS

The introduction of new technologies is accompanied by a shift of demands. Demands and workload will change in the areas of:

- Energy
- Information
- Organization
- Equipment
- Work Place
- Environment

The composition of demands has to be designated with respect to human possibilities and limitations.

METHODS

- Ergonomic Job Description Questionnaire
- Performance Measures
- Physiological Measures (electromyogram, electrooccculogram, heart rate, arrhythmia)

CLASSIFICATION OF WORKLOAD BY ANALYSIS OF DEMANDS

Thesis

Evaluation workload should be analyzed together with task-oriented workloads. Typical combinations of workload factors are to be described to point out areas for further research.

Methods

- Ergonomic Job Description Questionnnaire
- Cluster Analysis
- Factor Analysis
- Demand Profiles

REDUCTION OF WORKLOAD BY ERGONOMIC KEYBOARD DESIGN

Thesis

Static and dynamic workload may be reduced through an ergonomic design of keyboards.

Methods

- Performance Measures (lateral/contralateral keying)
- Physiological Measures
- Literature Research

SUPERPOSITION OF CLIMATE AND INFORMATORY WORK

Thesis

Performance and physiological homeostasis vary with climatic and informatory workload. Recovery periods will depend on composition of workload factors.

Methods

- Performance Measures
- Physiological Measures
- Subjective Rating
- Model Development for the Estimation of Recovery Periods

NEW TECHNOLOGIES IN TEXT PROCESSING AND THEIR IMPACT ON MAN (1979-1981)

Abstract--New technologies are classified due to their degree of automatization. In field studies task analysis is conducted in different branches of industry and administration. Tasks are clustered to similar groups of job demands. For these groups, data of stress-strain measurements over 8 hours were recorded and assessed. Unfavorable job demands could be isolated and proposals for designs could be given.

ANALYSIS AND DESIGN OF CONTROL-TASKS IN A TV STATION (1980-1981)

High job demands (perception, communication, static work, working hours, climate) were isolated for different jobs. Based on physical and electrophysiologic measurements as well as subjective rating, a new design for the control tasks was proposed.

ERGONOMIC DESIGN OF KEYBAORDS (1979-1981)

Material of keyboard design was collected from literature. Literature was coded and stored in an information and documentation system. Laboratory research on stress reactions due to design parameters lead to design proposals for typewriter keyboards.

SUPERPOSITION OF INFORMATORY WORK AND CLIMATIC STRESS (1977-1982)

Performance and strain reactions were recorded during superposition of stress factors. Maximal endurance limits could be laid down. With regard to physiologic measures and endurance limits, rest periods can be proposed depending on (1) difficulty of informatory work, (b) climatic stress, and (c) duration of work.

SUPERPOSITION OF INFORMATORY WORK AND VIBRATION (1976-1982)

For crane driving tasks on a simulator and superimposed vibrations, maximal endurance limits are laid down. Rest periods with regard to performance and strain will be derived. The results will be validated in field studies.

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HEART RATE MEASURES

A pilot's heart rate is monitored routinely during flight trial at Bedford where workload estimation is an important requirement. Results are used primarily to augment a pilot's subjective opinion and to identify rapid or short-term changes in levels of workload. Current flight trials include evaluation of approach aids for Sea Harrier, Category 3 approaches and landings, and head-up display.

A recently introduced rating scale based on the Cooper-Harper Handling Qualities rating scale is being used and ratings from a number of flight tasks compared with heart rate. Early results are encouraging.

Further research into the value of heart rate as a measure of aircraft handling workload is being undertaken on an "opportunity basis." Three different types of high performance aircraft are being compared for workload during approach and landings and during formation flying. Test pilots fly each type and rate the workload for comparison with their heart rates.

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We have no projects in mental workload. However, several of our flight management studies have included mental workload in models and/or measurements. Workload is only one aspect of our overall objectives.

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Research is undertaken on joint performance of several tasks at once; and the properties of the tasks, allowing or prohibiting simultaneous performance, are studied.

Research is undertaken and the feasibility of the P3 component of the Evoked Potential (EP) as a measure of workload during automobile driving is assessed. The EP is obtained to a signal counting task, carried out while driving.

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WORKLOAD MEASUREMENT METHODOLOGY CATALOG

The contractor conducted a comprehensive state-of-the-art survey and analysis of operator workload measurement methodology, research, and applications. The effort included a critical evaluation of the relationships between operator workload measurement requirements in aircrew systems and a catalog of available methodologies. The results of this effort are a significant factor in the future planning of RDT&E objectives in support of aircrew workload measurement requirements.

WORKLOAD ASSESSMENT DEVICE (WAD)

The contractor designed, fabricated, installed, and functionally checked out a workload assessment device to measure and analyze operator workload levels in flight. The effort included development of system hardware, software, and task procedures to collect and analyze data utilizing an item recognition task previously developed for the Air Force (AFAMRL). The device is presently installed in an NT-33A aircraft for in-flight display evaluations on the Display Evaluation Flight Test (DEFT) Program.

ANNOTATED BIBLIOGRAPHY OF OPERATOR WORKLOAD ASSESSMENT TECHNIQUES

In an attempt to review and select the appropriate technique to measure operator workload levels in aircrew systems, a survey and analysis of available workload measurement methodologies was conducted by Systemetrics, Incorporated, under Contract N00421-77-C-0083. A first report entitled, "Survey and Analysis of Operator Workload Assessment Techniques," was issued in September 1978. The report contained a bibliography of over 400 documents related to T&E techniques. The purpose of this procurement is to develop a companion report containing an updated bibliography of abstracted workload techniques. The annotated bibliography will be used as a cross-reference index for selecting candidate aircrew workload assessment measures for in-flight evaluation of man-machine systems. The proper use of the bibliography will impact the test and evaluation of all current and future military aircraft.

VOICE STRESS ANALYSIS

The project will develop an automated measure of stress based on voice analysis, which will be appropriate for human performance tasks involved in aviation, and which can be used without attaching equipment to a performer. Initial research has shown the feasibility of a vocal measure using a commercial instrument, the Psychological Stress Evaluator (PSE). The present project will (1) automate the procedure used in PSE analysis; (2) upgrade

this procedure through testing of relevant field-data against original laboratory data (involving a standard workload task); and (3) test the resulting measure on vocal data from projects at NASA/Ames and the NAVAIRTESTCEN.

VOICE STRESS ANALYSIS AS A MEASURE OF OPERATOR WORKLOAD

This study attempted to determine if the PSE could be used to detect the amount of situational stress in the voice while subjects performed a four-choice information processing task at different presentation rates. The 42 subjects were divided into Group I--Jet, Group II--Prop, and Group III--Staff. A Response Analysis Tester (RATER) presented a four-choice discrimination task in which the subjects were required to match a response key to each of four stimuli (Numbers 1, 2, 3, and 4) appearing in a display window. The sequence of stimuli was randomly presented in an automatic-paced mode for nine 1-minute tests. The stimuli presentation rates were set at one symbol per 1.5 seconds, 0.75 second, and 0.50 second. During the first three tests, the subjects were instructed to press the correct key and not verbalize the number. During the next three tests, the subjects verbalized the number and simultaneously pressed the correct key. At the end of each block of three tests, the subjects estimated self-performance as percent correct and rated stress on a scale of 1 (no stress) to 7 (high stress). Voice signals were initially recorded on magnetic tape, then processed through filtering circuits and displayed on a strip chart for subsequent visual analysis and interpretation. A subjective scoring criterion was established and then translated into electronic equivalents and automated on a Varian 73 computer for voice pattern recognition analysis. Significant main effects for percent-correct response were obtained for groups, presentation rate, and groups X presentation rate interaction. No significant differences were found in the correct responses of the subjects when the number was verbalized or not verbalized. The Staff group produced significantly fewer correct responses than either the Jet or Prop groups at the 0.75 second rate. Voice stress analysis showed significant correlations with performance scores and stress ratings of a selected pool of subjects (N = 12). The results were discussed as to the potential application of an objective, reliable, sensitive, and nonobtrusive measure of stress in vocal communication systems that require operator workload assessments.

EVALUATION OF A PILOT WAD TO TEST ALTERNATE DISPLAY FORMATS AND CONTROL STABILITY VARIATIONS

This in-flight research project evaluated the utility of a WAD to measure pilot workload for approach and landing tasks under simulated instrument meterological conditions, alternate Head-Up Display (HUD) formats, and control stability variations. The flight tests were conducted in an NT-33A research aircraft, extensively modified for the Air Force and Navy by the Display Evaluation Flight Test Program. The hardware, software, and test procedures associated with the WAD function efficiently with only minor descriptions and minimum pilot distraction. The project established the feasibility of using an item recognition task as a measure of sensory-response loading and reserve information processing capacity while flying

precision approaches. The results indicate an appreciable increase in reaction time and errors on the secondary task flown with degraded handling qualities as compared to ground baseline measures and good handling qualities. The pilots showed more mental reserve capacity when flying pictorial/symbolic HUD configurations, as compared to conventional HUD formats with standard scales and alphanumerics. It is recommended that further evaluations be conducted to establish the efficiency of utilizing the WAD to measure mental workload in a variety of aircrew tasks.

EVALUATION OF A PILOT ASSESSMENT DEVICE TO TEST
ALTERNATE DISPLAY FORMATS FOR AIRCRAFT CARRIER APPROACHES

This in-flight research study is a follow-on project to contract N0042179M-3660 to measure pilot workload for aircraft carrier approach and landing tasks. The flight tests were conducted at the NAVAIRTESTCEN using an Air Force modified NT-33A aircraft, laser tracking system for time-space-position data, the fresnel lens guidance mirror, and the DEFT programmable HUD graphics. A total of 10 flights were flown by four F-18 pilots using an F-18 based HUD and a pictoral Klopfstein display. These data are currently being analyzed.

CROSS-COUPLED INSTABILITY TASK (CCIT)

The contractor will design, fabricate, install, and functionally test the CCIT to measure and analyze pilot workload levels in flight. The effort will include advanced development and production of novel system hardware, software, and task procedures to collect and analyze simulation and in-flight data. The advanced development CCIT is based on an earlier prototype model developed for the National Aeronautics and Space Administration. The CCIT measures the tracking accuracy of the unloaded operator, adjusted for each individual's own baseline performance, and the excess control capacity when loaded by a selected combination of primary and secondary tasks. It is planned that the CCIT will be utilized during simulation of a precision flying task involving a control/display problem of sufficient magnitude requiring excess operator loading.

ADAPTIVE, CROSS-COUPLED WAD

The WAD developed under a previous contract (Systems Research Laboratories, Inc.) will be modified to provide options for an adaptive secondary task that can be cross-coupled to select flight parameters. An added feature will be an expanded statistical routine with mass storage capacity on a floppy disk. A unique troubleshooting software module will provide in-the-field diagnostic capabilities via a dial-up modem. Also, an improved speech synthesizer will be added to the WAD to furnish an audio presentation through the headphones.

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WORKLOAD DEFINITION

We have been engaged in two general programs in recent times. One has been concerned with the basic philosophical issues of the definition of mental workload as a conceptual schema. Our effort has been directed toward analysis of the modeling requirements for estimation of the load imposed by definable hypothetical systems which can be themselves simulated on a computer and operated by a model of the human operator.

COMPARISON OF SECONDARY TASK AND SUBJECTIVE METHODS

At a more pragmatic level, we have been making direct experimental comparisons between secondary task methods and subjective estimations for some simple tasks based on a TV "Pong" same. The general conclusion seems to be that subjective estimation by the operator doing the task is more consistent than the measures obtained by secondary tasks. Since the ultimate validity of any technique is the subjective one, it should be the case that subjective methods will prevail for field work except in cases (labor-management problems, for example) where objective methods are required.

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SUBJECTIVE WORKLOAD ASSESSMENT IN SIMULATED IFR FLIGHT

A cooperative project with Professor R. Simpson under FAA/DOT sponsorship had resulted in the development of a three-dimensional workload rating scale. It is now being evaluated in simulation experiments. Several reports have resulted, including a master's thesis by J. Katz.

MENTAL WORKLOAD IN FLIGHT MANAGEMENT

Using an experimental multitask paradigm developed by K. Tulsa in our laboratory several years ago, B. Daryanian has obtained subjective workload ratings for monitoring/control tasks composed of 27 combinations of three parameters: rate at which new tasks are imposed, time available for doing the tasks, and efficiency in doing the tasks. Rate at which new tasks are imposed had high correlation with subjective workload; the other factors had none. This work resulted in B. Daryanian's master's thesis.

BASIC RESEARCH IN HUMAN SUPERVISORY CONTROL

Includes mental workload as key factor in performance of human-computer-system control. Funded by ONR. Experimental techniques involve on-line computer simulation and computer-mediated performance measurement and subjective scaling in a variety of contexts.

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SUBSIDIARY RADIO COMMUNICATIONS TASKS

Due to problems associated with primary task intrusion and operator acceptance, many secondary task methods of assessing operator workload are difficult to employ during the later stages of aircraft system development. In order to develop a secondary task methodology appropriate for high fidelity simulation and in-flight test, the concept of using performance on subsidiary radio communications tasks as a measure of workload is presently under evaluation. Communications activities are an integral part of an aircrew member's task environment and are normally assigned a priority which is high yet secondary to other flight duties. Furthermore, the verbal and manual responses to radio messages are easily recorded and experimentally separable from other activities. Analytical, subjective, and hybrid scaling techniques have been employed to estimate the loading associated with realistic communications tasks derived from interviews with combat pilots. Performance evaluations are presently underway to assess the sensitivity of these tasks to rudimentary flight control workload and to generate criterion measures for evaluation of the a priori scaling results. The results of this effort will be used to develop guidelines for the design of secondary communications tasks tailored to specific system and mission contexts.

EVALUATION OF THE INTERVAL PRODUCTION TASK

Michon's (1966, Ergonomics) interval production task yields a workload measure which has received little recent experimental attention. The IPT requires subjects to generate a continuous series of time intervals by emitting a motor response at a consistent rate within the limits of one to three responses per second. The variability of interval duration is used as an index of primary task workload. The task is inherently simple, requires no sensory input, and offers a variety of possible response modes. Consequently, the IPT should minimize primary task interference. A further advantage is that the IPT does not seem to act as a reserve capacity secondary task. Instead, it appears to index load in a manner analogous to physiological metrics. In a current effort, the IPT is being evaluated for sensitivity to loading in both perceptual and motor dimensions. Alternate response modalities are also under investigation. Preliminary results indicate that the IPT produces little interference, is sensitive to task demand, and can track changes in workload produced by shifts in operator strategy.

METRIC EVALUATION PROGRAM

A sub-element of the AFAMRL workload program has been established to improve methods of assessing the utility of proposed secondary tasks and subjective workload metrics. The program is presently focused on the development of a standardized set of primary tasks selected on the criteria of being representative both of tasks which exist in Air Force systems and of the multiple dimensions of cognitive activity in which the human information processing system engages. The primary task set will be used to determine the types of tasks and mental functions a particular candidate metric can assess, its relative sensitivity to loading in those dimensions, and the degree to which it interferes with primary task performance. Standard experimental methodology and statistical analysis techniques are also being designed to permit timely, thorough, and comparable evaluations to be performed on any of a variety of proposed workload measures.

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PROJECT I

This project emphasizes quantitative methods for assessing intellective overload. The human transfer function is measured in a psychophysical workload context to determine individual load carrying capacity and intellective load carrying threshold.

PROJECT II

The intellective load placed on the operator of a system is measured to assess areas (in system employment) of operator overload and underload. The results are used to derive areas of needed system redesign/modification.

PROJECT III

The contribution of cognitive stress to intellective overload is assessed along with other variables such as shift length, work-rest cycle, group factors, diurnal rhythm, etc. The result is a measure of anticipated performance degradation due to these factors.

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WORKLOAD MODEL

A paper has been written to present some reflections about the problem of mental load and the measurement of the level of mental load. A general model of the relation between mental control effort and performance is given. Some connotations are made regarding the notion of mental capacity.

The model proposed is suggested to be applicable in the particular man-machine situation of an arm amputeed patient using a prosthesis. Pilot experiments with the aim to develop methods to measure the control effort in using a prosthesis is given as an example of the application of mental load measures.

At the end of this paper some questions are raised as to the factors which may restrain progress in mental research.

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THE ELUSIVE GOAL OF MEASURING PILOT WORKLOAD
IN GENERAL AVIATION

The multidimensional nature and complexity of tasks involved in piloting a modern aircraft are well known in the aviation field. What has been unclear and remains so is how to reliably measure both pilot workload and performance, which may well be different edges of the same sword.

The approach of the Federal Aviation Administration (FAA) Technical Center toward these concepts involves developing the tools necessary in order to evaluate the impact of systems changes in general aviation aircraft. The primary question to be answered is whether or not changes will affect the behavior of human operators. Currently the workload/performance effort is being made under a program titled "The Cockpit Display of Traffic Information."

Research is proceeding based on a pragmatic rather than highly theoretical measurement philosophy. It is assumed that traditional postflight questionnaire techniques may have been necessary, but insufficient indicators of pilot workload and a more viable "real-time" method are required. It is also assumed that many of the distinctions that have been made in the literature concerning types of meaurement have often artificially dichotomized variables. For example, referring to all questionnaire and rating scale techniques as totally subjective ignores levels of subjectivity and

objectivity which can vary based on experimental methods and procedures. We assume that if a pilot is asked in a systematic fashion how hard he/she is working, the response will be a holistic one. The pilot will not discriminate between internal physiological/psychological processes and overtly physical tasks of manipulating the aircraft.

Based on this monatomistic measurement philosophy, a series of experiments has begun to determine if people are willing and able to make workload judgments during the course of primary task performance. A goal has been set to establish a series of measures along continuums of objectivity and subjectivity.

The first experiment in the series employed a nonflying, critical tracking task in which both pilot and nonpilot groups were asked to maintain a point of light in the center of a CRT display. During the task, participants were queried every minute by a tone and were told to respond by pressing one of an array of 10 buttons to provide a workload assessment ranging from one (very easy) to 10 (very hard). This was considered the more subjective measure while response latency was the more objective measure. Four task difficulty levels had been established and were administered in a counterbalanced design. Results indicated that workload judgments corresponded very well to the four difficulty levels. Although responding during task performance was somewhat obtrusive, participants were able to respond without a noticeable decrement in performance.

The second experiment introduced a "flying" task using a Link general aviation trainer (GAT). Three levels of difficulty were designed by varying the initial clearance complexity, the level of air traffic control, and in-flight emergency. A digital computer was employed to query the pilot through presentation of a tone and to record responses and latencies. Both these variables were significantly different across the three levels of difficulty. Pilots were again able and willing to make these judgments during flight. A task frequency tally showed that there were two areas of pilot behavior which increased in frequency as difficulty increased. These were communication and navigation.

This experiment was dependent on a fixed minicomputer for workload data collection. Plans for the future involve using a microcomputer in an airborne configuration to provide query probes and collect data from pilot/copilot and an observer through input keyboards designed for that purpose.

Performance research is just beginning at the FAA Technical Center. It will be based upon a mixture of Automated Performance Measurements (APM) and traditional instructor pilot checklist/rating scale methods. An instrumented GAT will be capable of recording 79 aircraft status and control parameters at a sampling rate of once per second. Initial studies will attempt to establish composite measures which will separate pilots based on their experience and training. This will hopefully lead to measures of performance on a continuum suitable for general aviation applications.

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BIOCYBERNETICS

Objectives for this project focus on study and evaluation of brain electrical activity (both transient and steady-state responses) for use as metrics in workload assessment and for rudimentary hands-off display quality optimization. For the first objective, sensitivity of the brain-evoked responses to sensory and cognitive parameters, especially reflected in amplitude and phase changes, will be analyzed to determine usefulness of the measures as aids in display design and subsystem evaluation. Alerting and warning systems will receive emphasis; discrete presentation of the warnings will provide stimuli for transient-evoked responses to determine how the information is utilized by the pilot (i.e., whether it is acknowledged, ignored, processing characteristics, etc.). Analysis of the sensory, cognitive, and motor parameters of the alerting and warning information systems will be conducted to determine which combinations of parameters effect optimal utilization of the displayed information. The purpose of this investigation is to validate the psychophysiological measurement techniques in other than a laboratory environment and to compile a design guide matrix which will enable the technique to be used during the design process.

The second objective focuses on the steady-state response. Steady-state brain electrical activity, evoked through sinusoidal modulation of display intensity, will be used for on-line monitoring of display image quality (intensity, contrast, etc.). In addition, an automatic feedback control system will be developed which will alter display image qualities based on evoked response characteristics.

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QUALIFICATION OF PILOT WORKLOAD VIA INSTRUMENT SCAN

The following describes work in progress on the use of visual scanning behavior as an indicator of pilot workload. The study is investigating the relationship between level of performance on a piloting task, the skill of the pilot, the level of mental workload induced by an additional verbal task imposed on the basic control task, and visual scanning behavior. The basic control task involved maintaining a general aviation flight simulator on a straight and level, constant sensitivity, Instrument Landing System (ILS) course with a low level of turbulence. A task employing an algorithm based on relative magnitudes of a sequence of numbers was used to increment the

subject's mental workload. The level of loading for various conditions was also estimated in an independent series of runs using a side task. The subject's lookpoint on the instrument panel during each ten-minute run was computed via a TV oculometer and stored. A total of 13 pilots of varying skill participated in two sets of experiments.

The results indicate an increase in fixation dwell times, especially on the primary instrument, with increased mental loading task. The amount of "staring" observed appears to depend on the level of skill of the pilot; skilled subjects appear to stare less under increased loading than do novice pilots. Sequences of instrument fixations were also examined. The percentage occurrence of the subject's most used sequences decreased with increased task difficulty for novice subjects but not for highly skilled subjects.

Analysis of the periodicity of the subject's instrument scan was accomplished using autocorrelation. Skilled pilots were found to scan their primary instrument in a periodic fashion. The period was related to the interval between number task presentation. A similar result was not observed in novice pilots. This finding suggests that skilled pilots may handle the additional loading task in a much more systematic fashion than do novice pilots.

Entropy rate (bits/sec) of the sequence of fixations was also used to quantify the scan pattern. It consistently decreased for most subjects over the four loading levels used. An exponential equation in task difficulty was found to be a good predictor of entropy rate. When solved for task difficulty, the equation provided an estimate of the level of task difficulty perceived by a subject. This estimate was used to quantify the workload of the subject.

Piloting and number task performance measures were recorded and a combined performance measure was computed. This was used in developing a model relating performance, skill, and mental workload. Entropy rate of the scan was used to quantify the workload and skill was estimated independently via a method based on pilot experience. The resulting exponential model fit the data well enough to suggest that this approach has promise in the valuation of interactions among these variables.

Wickens, Christopher D.
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TASK INTEGRATION AND WORKLOAD ASSESSMENT:
APPLICATIONS OF A STRUCTURE-SPECIFIC RESOURCES
MODEL OF HUMAN INFORMATION PROCESSING

This is a programmatic effort to relate theoretical models of attention to measures of task workload, and guidelines for integrating tasks in complex

environments. The model we adopt (and are validating) is a multiple resource model that assumes attention is not scalar but a vector quantity where dimensionality is defined by two stages of processing, two codes of processing (verbal versus spatial), and by processing modalities. With regard to workload, we ask how task demands imposed upon the various attentional resources in combination concatonate to generate single scalar measures of workload (subjective ratings, heart rate variability, primary task performance); and how measures of single task workload predict task performance in combination. With regard to task integration, we demonstrate how options in task design that utilize separate resources (e.g., spatial coding, auditory displays, and speech output), can improve the efficiency of dual task performance.

THE EVENT RELATED BRAIN POTENTIAL AS AN INDEX OF ATTENTION ALLOCATION AND TASK WORKLOAD

This effort focuses on the unique information that the event-related brain potential can provide concerning (1) the locus of processing demands of a concurrent task within a multiple-resource conception, (2) the allocation of attention to events in complex auditory and visual displays. The term "unique" stresses the extent to which information derived from the ERP is unavailable from conventional manual and vocal responses. This is a part of a longer programmatic effort by the Cognitive Psychophysiology Laboratory concerning the contributions of the ERP to advances in human engineering. Research support has been provided by ARPA, Air Force AMRL and OSR.

DISSOCIATION EFFECTS/SECONDARY STERNBERG TASKS

At Illinois, we are continuing our efforts to compare behavioral (Sternberg task) and physiological (event-related potential and sinus arryhthmia) workload measures with each other, and with subjective workload estimates in a variety of settings. One issue focuses on the dissociation between subjective measures and secondary task measures, i.e., what does it mean when two conditions are discriminated by one measure but not by the other? We observe such dissociation when we compare workload changes induced by adding more tasks and by increasing the difficulty of a single task.

A second issue concerns the exploration of the Sternberg task as a secondary task workload index. We are interested in the information provided by slope and intercept measures of the Sternberg RT function and the way in which these relate to "central processing," input and output load. In particular, we have examined several applications of this task to flight workload and noted the prevalence of decreasing slopes with additional task workload. This somewhat counter-intuitive result, we believe, may be a consequence of (1) the input/output modality of the task employed (auditory/vocal versus visual/manual), and (b) the mismatch between a primarily spatial flight task, and a verbal-languaged-based Sternberg task (letter search). As a consequence, we are exploring an auditory-spatial variant of the Sternberg task used in the context of various maneuvers on the GAT 2 general aviation simulator.

Wierwille, Walter W.
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COMPARISON OF WORKLOAD ASSESSMENT PROCEDURES
IN A DRIVING SIMULATOR

Five methods of measuring mental workload (secondary task performance, visual occlusion, cardiac arrhythmia, subjective opinion rating scales, and primary task performance) were compared for sensitivity to changes in operator loading. Each was used to differentiate among low, medium, and high levels of workload defined in terms of the application point of cross-wind gusts in a driving task.

The driving task was produced using an automobile driving simulator with a six-degree-of-freedom computer generated display, a 4-degree of freedom physical motion system, and a four-channel sound system. Techniques of mental workload measurement that have shown promise in previous studies were used as a between-subjects factor, and subjects were presented with a within-subject factor of wind gust placement. Gusts at the front of the vehicle represented high workload levels, and gusts toward the center of the vehicle represented progressively lower levels of workload.

The results showed significant differences among workload levels for subjective opinion scales and primary performance measures of lateral deviation, yaw deviation, and steering reversals. A relative sensitivity estimate of these would be from highest to lowest sensitivity, steering reversals and yaw deviation, rating scales, and lateral deviation. The techniques of occlusion, cardiac arrhythmia, and secondary task performance yielded no significant workload effect.

MEASUREMENT OF PSYCHOMOTOR WORKLOAD IN SIMULATOR
DRIVING BY A SECONDARY TASK--SUBSEQUENT COMPARISON OF
PRIMARY AND SECONDARY TASK MEASURES OF WORKLOAD

Six subjects drove a simulated vehicle with normal automobile handling and another six drove with degraded handling (slow response). Steering ratio and disturbance level were adjusted within each set of six subjects. A secondary task consisting of reading random digits aloud from a single-digit dashboard display was used to assess workload. Using a technique similar to that of Knowles (1963) and McDonald (1973), it was found that workload increased significantly as disturbance level increased. Furthermore, workload increased significantly with degraded vehicle handling. In contrast, increasing steering ratio did not produce a significant change in workload. These results indicate that secondary task method can be used to assess the major effects of simulated vehicle handling on driver workload. Problems remain, however, in designing more sensitive secondary task measures.

Because the secondary task measure appeared less sensitive than desired, driving performance measures recorded during the same experiment were later analyzed. Particular emphasis in examining the driving performance data was placed on (1) determining the degree of intrusion of the secondary task on the driving task as a function of the independent variables, and (2) on comparing the sensitivity of the primary and secondary task measures. The results showed the secondary task does not intrude significantly upon the driving task performance at low workload levels, but that it does significantly intrude at high workload levels. Also, when the four primary task measures were analyzed for sensitivity to the independent variables, new information was obtained indicating greater sensitivity than is obtained with the single secondary task measure. Steering ratio, for example, is found to affect performance at high disturbance levels--a result not obtained in examining the secondary task by itself. The merits of primary and secondary task performance analysis are discussed, and suggestions are made for future work.

SURVEY AND ANALYSIS OF OPERATOR WORKLOAD TECHNIQUES

Over 400 references relating to operator mental workload were selected and classified according to a two-dimensional scheme including workload methodology and universal operator behavior. Twenty-eight specific techniques of assessing workload by means of subjective opinions, spare mental capacity, primary task, and physiological measures were cataloged. The catalog summarizes critical criteria that need to be considered in the flight test and evaluation environments and describes each technique in terms of theory and background, description of necessary method/apparatus, area of application and example, limitations, and suggested RDT&E follow ups.

AN ANNOTATED BIBLIOGRAPHY OF 650 WORKLOAD DOCUMENTS

An annotated bibliography on operator mental workload was developed with supporting information. This bibliography was based upon two literature searches, one performed in 1977 in support of a survey and analysis catalog (AD A059-501) and one performed in 1979 as an update.

Each literature search citation presented contains reference information, an abstract, a numerical workload technique category classification, a numerical operator behavior classification, and a group of word descriptors. Workload methods are divided into 28 specific techniques in four major categories: opinion, spare mental capacity, primary task, and physiological. Applicable operator behaviors are similarly divided into categories.

The descriptors associated with each citation designate the general workload classification, the specific workload classification, the type of presentation, the type of facilities used, and the potential aircrew application. Over 600 citations are presented. Two indexes are also provided. The first is a workload technique index and the second is an experimental facility index. It is concluded that periodic updating of the bibliography will be required and that attention should be directed toward computerizing future workload bibliographies.

COMPARATIVE EVALUATION OF VARIOUS MEASURES TAKEN FROM A SINGLE SECONDARY TASK

Problems have been encountered in previous research in developing a secondary task measure of mental workload that is both sensitive and stable. Ordinarily a single measure of secondary task is analyzed as an indicator of difference in workload. The purpose of this project was to determine whether alternate measures taken from a single secondary task might prove more sensitive. Twelve subjects participated in the experiment involving a primary task (meter pointer nulling) and a secondary task (reading random digits aloud). The independent variable (primary task difficulty level) was adjusted by changing the number of meters that had to be monitored (2, 3, or 4 meters). Dependent measures were taken on the (1) number of random digits spoken (usual workload formula), (2) longest interval between spoken responses, (3) longest consecutive string of spoken digits, and (4) the number of "triplets" spoken. Results show that the dependent measures (1), (3), and (4) were significant with (1) being the most sensitive.

COMPARATIVE EVALUATION OF THE SENSITIVITY, TRANSFERABILITY, AND INTRUSION OF A VARIETY OF WORKLOAD ESTIMATION TECHNIQUES IN AIRCREW TASKS

The purpose of our present work, sponsored by NASA-Ames, is to examine the sensitivity, intrusion, and transferability of a variety of workload assessment techniques. The study will use four different simulated piloting tasks, emphasizing psychomotor, perceptual, mediational, and communications aspects. Pilot loading levels wll be systematically adjusted. Our simulation facility is a GAT-1b that has been modified and instrumented for workload estimation techniques measurement. The flight simulator itself has 3 degrees of physical motion and a full complement of IFR instruments.

Recently we completed the experiment emphasizing the psychomotor aspect of flight. Instrument-rated pilots flew instrument approaches under three combined settings of the independent variable: Increasing turbulence and decreasing longitudinal stability. Twenty different workload measures were taken between the outer and middle markers, only five of which showed statistically reliable changes as a function of the independent variable. Included in the five were two rating scales, one measure of control input activity, heart rate, and one measure of time estimation. The results of the experiment are to some extent surprising, for they indicate that several "accepted" measures of workload are not reliably sensitive to the kinds of psychomotor load which pilots encounter.

We are currently planning the perceptual and mediational (cognitive) experiments. In both cases pilots will fly the simulator in the simple task of maintaining heading, airspeed, and altitude. For the perceptual task, they will also perform a forced-pace visual search task presented through the windscreen using an Ektagraphic display. The complexity of the search task will become the independent variable. The mediational task, navigation problems will be presented. The problems will be forced pace, but will not require computational aids. We expect to have the results of these two experiments in the spring of 1982.

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Ph. (513) 317-7421

STEADY-STATE EVOKED RESPONSE

Steady-state evoked responses (ER) are being tested as to their utility as a measure of mental workload. Several cognitive and motor tasks are being used which each have two or three levels of difficulty. ER measures of phase lag and amplitude recovered during the time subjects engage the various tasks are correlated with the level of difficulty. High frequency (40 to 60 Hz) flicker is being used to elicit the ERs; these have the advantage of being close to fusion frequency and thereby relatively unobtrusive into the primary task.

TRANSIENT-EVOKED RESPONSE

Transient-evoked responses are being used to assess pilots' responses to emergency situations in a motion-based simulator. Single-trial evoked responses in response to auditory tones are used to determine whether or not the pilot recognized the onset of the emergency situation in time to take corrective actions. Eye movement analysis is also being used to study point-of-regard during these episodes.

SECTION IV

WORKLOAD LABORATORIES

This section is a listing of laboratories and research groups engaged in programmatic research on mental workload. The entries are arranged alphabetically by laboratory name. A mailing address is provided and the laboratory director as well as other personnel are identified. In addition, entries may include a brief description of the laboratory's research interests and goals.

AFAMRL WORKLOAD AND ERGONOMICS BRANCH

AFAMRL/HEG
Wright-Patterson AFB, Ohio 45433

Col. Robert D. O'Donnell

Mr. Gary Reid, Mr. William Pearson,
Dr. Clark Shingledecker, and Dr. G. Wilson

The lab is dedicated to developing and implementing workload assessment techniques for specific application to Air Force systems. Separate laboratories are involved in development of behavioral/performance measures and neuropsychological/physiological measures. The laboratory mandate involves conducting studies in-house, contractual efforts, and validation studies in simulators and field units. In addition, workload standards for all Air Force systems will be generated and MIL-Specs for acceptable workload will be produced by CY85.

APPLIED PSYCHOLOGICAL SERVICES

404 East Lancaster Avenue
Wayne, Pennsylvania 19087

A. Siegel

P. Federman, R. Leahy, M. Pfeiffer, F. Kopstein, and N. Madden

The work emphasizes methods for measuring intellective load and assessing the effects of overload on performance. A factorial approach is taken.

BAC CREW SYSTEMS (2-3755)

P.O. Box 3999, M.S. 82-87
Seattle, Washington 98124

Mr. W. U. Hebenstreit

Dieter W. Jahns, Judi Qualy, George Boucek, and Charles A. Anderson

Develop workload assessment/prediction methodology for commercial and military aircraft operability certification. Investigate the utility and sensitivity of various human performance and physiological parameters for scaling operator workload in realistic crew/aircraft/mission contexts. Both analytical and crew-in-the-loop simulation techniques are used.

CENTER FOR WORK SAFETY AND HUMAN ENGINEERING

Industrial and Management Engineering
Technion, Haifa, Israel

Dr. Daniel Gopher

Dr. David Navon and Dr. Peretz Lavic

CENTER FOR APPLIED PSYCHOLOGICAL STUDIES

Old Dominion University
Norfolk, Virginia 23508

Dr. Ben B. Morgan, Jr.

Dr. Glynn D. Coates, Mr. Peter S. Winne,
Mr. Michael Secunda, and Dr. Raymond H. Kirby

Conduct research dealing with the assessment and enhancement of human performance in man-machine systems. These efforts are directed generally toward improving systems efficiency by increasing the understanding of basic capabilities of the human component in the system and the factors--including workload--that influence these capabilities. We are particularly concerned with the effects of temporal, biological, and environmental stressors on human performance individual differences in performance capabilities and responses to stress and complex skill acquisition, retention, and maintenance. Much of our research is conducted with the multiple-task methodology of the synthetic work approach to performance assessment. This methodology routinely involves the assessment of performance at different levels of workload.

CREWSTATION DESIGN FACILITY

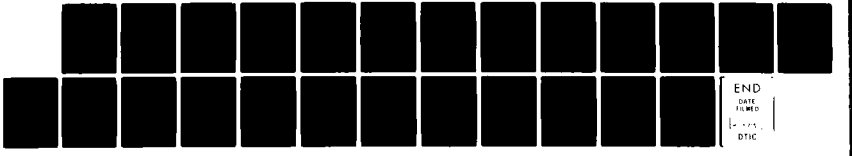
ASD/ENECH
Wright-Patterson AFB, Ohio 45433

Richard Geiselhart

Larry Ivey, David Gunning, Capt. Mike Manning, and Jan Gavern

The Crewstation Design Facility is equipped with three full mission flight simulators: an A-10, a FB-111, and a KC-135. The simulators are used to conduct applied human factors research in support of various system program offices (SPOs) at Wright-Patterson. The research problems cover a wide range of topics such as crewstation layout, control/display design, automation, terrain following, air-to-ground attack, display symbology, etc. Although the facility is not dedicated to developing new workload measurement techniques, workload is almost always a major concern in the research efforts. The facility personnel are continuously applying different workload measurement techniques in the various research projects.

AD-A122 428 REGISTER OF RESEARCH IN PROGRESS ON MENTAL WORKLOAD(U) 2/2
AIR FORCE AEROSPACE MEDICAL RESEARCH LAB
WRIGHT-PATTERSON AFB OH T R METZLER ET AL. JUL 82
UNCLASSIFIED AFAMRL-TR-82-42 F/G 5/9 NL



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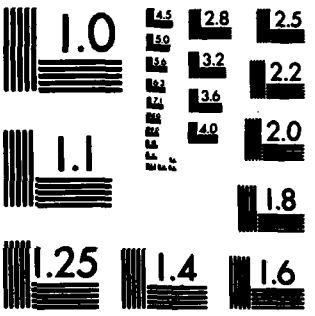

CREW SYSTEMS ENGINEERING GROUP

AFWAL/FIGR
Wright-Patterson AFB, Ohio 45433

Richard Moss

Larry Butterbaugh, Evelyn Blanch, and Lt. Dan Basehore

The Crew Systems Engineering Group has the objective of providing crewstation design guidelines and preliminary crew procedures for candidate aircraft. This technology includes developing a physical representation of the cockpit design to include control-display formats and workspace layout. The mission scenario is analyzed in terms of necessary systems and associated crew tasks, and these are systematically arranged over time to provide an accurate task time line with which to evaluate the design effort. Designs are iterated and evaluated with increasing fidelity from mockup through dynamic pilot-in-the-loop simulation. The process carries through to establishing the technology tradeoffs between crew size/workload and avionics automation/sophistication. The Group is also responsible for such functional areas as crew workload measurement and problem analysis for current as well as future aircraft and major systems.

COCKPIT INFORMATION SYSTEMS--WORKLOAD ASSESSMENT

NASA-Ames Research Center
Mail Stop 239-2
Moffett Field, California 94035

Sandra G. Hart

Kathleen Bird, Laura Lapp, Mike Bortolucci,
David Suzuki, and Cheryl Chapel

The global purpose is to develop a methodology for measuring pilot workload in simulation and in-flight research. The immediate aim is to develop subjective rating scales, primary performance measures, and possibly unobtrusive secondary measures, to use in evaluating the impact of cockpit displays of traffic information on pilot and controller workload. In providing these measures, theoretical research will be supported, and more general applications will be developed. The hope is that by stepping back, redefining the problem, and starting back with the pilot and looking at what he does, thinks, and feels and relating this to what he says (and what we measure) about his workload, we can make some headway. Simply trying more secondary tasks or wiring up subjects for more physiological output isn't the solution. The reason that the different subjective, objective, and physiological measures correlate with each other so poorly is that each one most likely taps a different aspect of the subjective experience of workload--some focusing on task demands, some on performance, some on stress and physical effort, some on perception, others on cognition, etc.--and most rely on the task requirements as a definition of load and performance as a definition of effort. Neither may be correct or valid.

CYBERLAB

Department of EE and CS
University of Connecticut
Box U-157
Storrs, Connecticut 06268

Professor D. L. Kleinman

Professor A. R. Ephrath

CYBERLAB was established in 1976 to provide an administrative and academic framework for the conduct of specialized theoretic and empirical research in the field of systems in general and, in particular, systems that include humans as components. The laboratory conducts analytical and experimental research on human performance in manual control and decision-making tasks.

DUNLAP AND ASSOCIATES, INC.

920 Kline Street, Suite 203
La Jolla, California 92037

Clyde A. Brictson, Ph.D.

Anthony P. Ciavarelli, M.A.

ENGINEERING-PSYCHOLOGY LABORATORY

Department of Psychology
University of Illinois
Champaign, Illinois 61820

Christopher Wickens

William Derrick, John Micilizi, Diane Sandry, and Roger Marsh

The Engineering-Psychology Laboratory is an interdisciplinary facility operated jointly by the Department of Psychology and Mechanical/Industrial Engineering. The Laboratory contains a GAT 2 general aviation simulator and three general purpose experimental computers, along with speech recognition and synthesis devices. It is devoted to research in basic issues of human performance, particularly as these pertain to aviation. Primary research activities relate to workload, divided attention, failure detection, and fault diagnosis.

FAA CIVIL AEROMEDICAL INSTITUTE, AVIATION PSYCHOLOGY LABORATORY, HUMAN PERFORMANCE UNIT

FAA-CAMI, AAC-118
P.O. Box 25082
Oklahoma City, Oklahoma 73125

Henry W. Mertens, Ph.D.

Nelda J. Sapp

GENERAL PHYSICS CORPORATION

1 Northgate Park
Chattanooga, Tennessee 37415

Ed Kozinstey

Julien M. Christensen

HUMAN FACTORS LABORATORY

University of South Dakota
Vermillion, South Dakota 57069

LCDR Helm

J. Stone

Scaling Mental Workload using category versus ratio scaling techniques.

HUMAN FACTORS TEST AND EVALUATION METHODLOGY DEVELOPMENT LABORATORY

Naval Air Test Center
Mail Code SY721
Patuxent River, Maryland 20670

Dr. Sam Schiflett

Dr. Carole Bohn, Cdr. Harv Gregoire, Ph.D., Mr. Dick Walchli, Mr. Art Weaver, Mr. Gave Intano, Mr. Keith Karn, and Mr. Gary Loikith

HUMAN PERFORMANCE LABORATORY

Engineering-Psychology Department
McDonnell Douglas Corporation
St. Louis, Missouri 63166

Dr. Frank Gomer

Dr. Larry R. Beideman, Dr. William Cody, and Dr. Kirmach Natani

HUMAN PERFORMANCE RESEARCH LABORATORY

Dr. Jerrold M. Levine

INSTITUT FUR ARBEITSWISSENSCHAFT

Petersenstr. 30,
6100 Darmstadt
Federal Republic of Germany

Prof. Dr.-Ing. W. Rohmert

Dr. E. Haider, Dipl.-Ing. R. Helbig, and Dr. P. Jenik

Basic research is done to validate physiological measures or in order to concentrate on isolated workload factors.

INSTITUTE FOR EXPERIMENTAL PSYCHOLOGY

Kerklaan 30, Haren
The Netherlands, G751NN

Dr. G. Mulder

Dr. L. S. Mulder, Dts. R. A. Brookhuis, Dts. H. Veldman, D. T. S. Bakker

The primary task of the Institute is to train students in Experimental Psychology. The research lines of the Institute are:

1. Research in Cognitive Skills
2. Psychophysiology of Mental Tasks
3. Applied Research (Psychological and Physiological Aspects of Driving; Psychopharmacology)

MAN-MACHINE SYSTEMS GROUP

Electronics Department
RISO National Laboratory
DK-4000 Roskilde
Denmark

Jens Rasmussen (plus five coworkers)

INTRODUCTION

This group is concerned with design and operational problems with safety and reliability in modern process plant. These have to do particularly with the distribution of tasks related to system protection between operations personnel and the plant instrumentation and control system as well as establishing means for including the human in systematic reliability and risk analyses.

MAN-MACHINE SYSTEMS LAB

Room 1-110 MIT
Cambridge, Massachusetts 02139

Prof. T. B. Sheridan

R. W. Simpson, W. Wood, and J. Tzelgov

Academic research laboratory staffed by graduate students, visiting scientists, and faculty. Devoted to experiments and modeling of man-machine interaction in ocean systems, robotics, nuclear power. and process control.

MENTAL PROCESSES LABORATORY/PSYCHOPHYSIOLOGY LAB--EEG/EOG

Human Factors Engineering
Douglas Aircraft Company
C1-253, Code 35-36
3855 Lakewood Boulevard
Long Beach, California 90846

R. F. Gabriel, Ph.D.

Robert T. White, Ph.D. and Michael A. Biferno, Ph.D.

The Mental Processes Laboratory is dedicated to research on mental workload. Of particular interest are the identification of mental processes that contribute most to cockpit workload; the quantification and meaurement of mental workload components; and the development of guidelines and criteria for the design of information displays that will minimize mental workload. The laboratory is directed and staffed by the Human Factors Engineering group. In addition to on-going research, the laboratory investigates specific mental workload problems referred by design groups and constantly endeavors to bridge the gap between basic and applied research. Both behavioral and physiological measures are being investigated.

MRC APPLIED PSYCHOLOGY UNIT

15 Chaucer Road
Cambridge CB22EF, England

Dr. I. D. Brown

Dr. D. G. Wastell and Dr. P. McLeod

Theoretical and applied research on normal human characteristics and performance, in order to advise governmental and other organizations on the design of work, tasks, and equipment.

NASA LANGLEY RESEARCH CENTER

Flight Dynamics and Control Division
Hampton, Virgnia 23665

Randall L. Harris, Sr.

Dr. Alan Pope, Amos Spadey, and Marvin Waller

Primary interest is to apply oculometer type data and pilot screening data with the pilot's screening data analysis technique to evaluate mental workload. Derived measures from information theory, called Entropy Rate, is also being used to validate these measured for mental workload. Currently one of the projects that is being used to help in this evaluation is a comparison of a Vertical Speed Indicator (versus the conventional dial type VSI).

NAVAL BIODYNAMICS LAB

Box 29407
New Orleans, Louisiana 70189

Dr. Channing L. Ewing

Drs. Thomas, Guignard, Ewing, Kennedy, Shannon, Bittner, and Carter

The effects of inertial forces on human responses. Inertial forces on all linear and angular acceleration. Human response--everything from skeletal to thinking and decision making.

OPERATIONS TRAINING DIVISION

AFHRL/OT
Williams AFB, Arizona

Col. Needhorn

Dr. Thomas Longridge, Dr. J. C. DeMaio,
Dr. Ernest Buckland, and Dr. Ronald Hughes

PERFORMANCE ASSESSMENT LABORATORY

Old Dominion University
Norfolk, Virginia 23508

Dr. Ben B. Morgan, Jr.

Dr. Glynn D. Coates, Dr. Raymond H. Kirby, and Mr. Peter S. Winne

The Performance Assessment Laboratory conducts research dealing with the assessment and enhancement of human performance in man-machine systems, particularly in industrial and military settings. Falling broadly within

the domain of Human Factors and Engineering Psychology, these efforts are directed toward improving systems efficiency by increasing the understanding of basic capabilities of the human component in the system and the factors that influence these capabilities.

Illustrative Problem Areas:

- Effects of temporal, biological, and environmental stressors on human performance.
- Synthetic work methodology in performance assessment.
- Psychomotor, perceptual, and information-processing capabilities of the human operator.
- Individual differences in performance capabilities and responses to stressors.
- Performance effects of circadian rhythms and menstrual cycles.
- Effectiveness of team training techniques.
- Skill acquisition and maintenance.

PSYCHOLOGY DIVISION, INSTITUTE FOR PERCEPTION

Institute for Perception,
TNO Soerterberg, The Netherlands

Prof. Dr. A. E. Sanders

Dr. A. W. K. Gaillard, Dr. P.Jorna, and Dr. W. H. Janssen

Interest in simultaneous performance of more than one task. Interest in electrophysiological measures of mental load. Both interests are materialized in basic laboratory tests as well as in applied settings like diving and automobile driving.

PTI-UNIT, UNIVERSITY OF STOCKHOLM

Box 5602, S114 86
Stockholm, Sweden

Gunnar Borg

The general interest of the group concerns theories and methods in scaling subjective effort and difficulty, performance measures of the same variables, and their physiological correlates. The theoretical and methodological interest is then combined with various applications in medicine, preventive activities, and rehabilitation in industries and in sports. New psychophysical methods are developed especially for quantitative evaluations of subjective intensity but also for qualitative aspects and dimension analysis.

RAF INSTITUTE OF AVIATION MEDICINE

Farnborough, Hampshire
United Kingdom GU14 6SZ

V. David Hopkin

R. M. Raylor, A. McClumpha, J. V. F. Berman,
and C. S. Narborough-Hall

The psychologists in the General Psychology Section of the Royal Air Force Institute of Aviation Medicine are concerned with the application of practical human factors knowledge, obtained from the literature and from their own research, to solve aviation problems in the air and on the ground. A current interest is the relationship between recent developments in cognitive psychology and practical problems, particularly of information processing, attention, memory, mental workload, and capacity. Human capabilities and limitations are related to task objectives, the physical environment in which the task has to be done, the standards to be achieved, the selection and training required, and technological developments. Current topics of interest include air traffic control systems, aviation maps, cockpit ergonomics, the effects on cognitive processing of minor departures from optimum physical environments, the etiology of errors, and the roles of man in highly automated systems. Although many practical problems require a short-term answer, longer-term studies which give continuity to the work are also conducted.

SYSTEMS RESEARCH LABORATORIES, INC. (SRL)

Human Factors Engineering Division
2800 Indian ripple Road
Dayton, Ohio 45440

Dr. Norman R. Potter

M. S. Crabtree, Dr. F. T. Eggemeier, J. C. Simons, Dr. J. S. Skelly

SRL is active in all three major areas of workload assessment--behavioral, physiological, and subjective. Staff experience includes a broad range of Army, Air Force, and Navy projects requiring workload assessment in applied settings as well as the development of workload metrics in both the field and the laboratory. SRL engineers and programmers design and build many types of systems for physiological recordings, presentations of primary and secondary tasks, and recording of human operator performance data.

SYSTEMS TECHNOLOGY, INC.

13766 South Hawthorne Boulevard
Hawthorne, California 90402

Henry R. Jex

D. T. McRuer, I. L. Ashkenas, R. W. Allen, W. F. Clement,
R. K. Heffley, R. A. Peters, and W. F. Jewell

Operator control strategy, workload, and human error measurement by intrusive and nonintrusive methods.

INTRUSIVE APPROACHES

Cross-adaptive task measure of excess control capacity based on cross-coupled instability using existing inputs/describing function analysis by finite Fourier transformation using injected test inputs; eye point of regard.

NONINTRUSIVE APPROACHES

Samples data correlation in time domain or phase plane using lease squares criterion with existing inputs and eye point of regard.

CONTROL STRATEGY MODELS

Metacontroller based on successive organization of perception (SOP) theory, including isomorphic models for compensatory, pursuit, and precognitive strategies and algorithmic models for the SOP and monitoring processes.

PERCEPTUAL MOTOR WORKLOAD MODELS

Excess control capacity, properties of describing functions, remnant, eye point of regard distributions.

USARTI AEROMECHANICS LABORATORY FLIGHT CONTROL DIVISION
HUMAN FACTORS GROUP

Director, U.S. Army Aeromechanics Laboratory
DAVDL-AL-C
207-5 Ames Research Center
Moffett Field, California 94035

Attention: David Key

Dr. Edward M. Huff

Dr. Robert H. Wright

The Aeromechanics Laboratory sponsors a man-machine integration research activity jointly with the NASA Ames Research Center's Helicopter/VTOL Human

Factors Office. Applied research on helicopter man-machine integration topics focuses on improved system design methods, concepts, and evaluations. The main areas of effort are helicopter pilot workload and performance, research flight simulation methods and requirements, helicopter control, and display technology.

VEHICLE SIMULATION LABORATORY

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Sidney Connor, John G. Casali, and Mans Rahimi

The general thrust of our present workload research is in experimental validation of a variety of workload estimation techniques. Vehicular environments are simulated and techniques are then examined. We are also working on refined rating scales and methods for examining short-term workload.

WORKLOAD RESEARCH GROUP

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To understand, measure, and predict mental and/or physical workload as a function of the characteristics of various types of tasks and man-machine interfaces. Emphasis is on applied as opposed to basic research; mental as opposed to physical workload; subjective as opposed to performance measures. Metric development and scaling are emphasized as part of the development of analytical workload estimation techniques. Primary applications to date have dealt with Naval aircraft, submarines, and other weapons systems. A key concept focusing the group's activities has been system effective operability, which is viewed as a function of task criticality, workload, and system technical effectiveness.

WORKLOAD RESEARCH GROUP

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Mr. Henry R. Jex

R. Wade Allen, James C. Smith, Warren A. Clement, Anthony C. Stein, and Richard A. Peters

One or more members of this group, with assistance from various staff members, act as team leader/members on basic and applied workload measurement projects. Members are two-thirds engineers and one-third engineer-psychologists. Interests cover experimental methodology, model development/validation, device development (e.g., the well known S. T. I. Critical Instability Task) and application to man/machine problems (e.g., displays, controls, drugs--the effects of environmental, task, and operator variables on workload).

SECTION V

POTENTIAL FUNDING SOURCES

This section was compiled from responses to a request for the names and addresses of organizations which have interests in mental workload problems and which may be sources of funding for relevant research. It should be noted that these entries reflect the opinions of the respondents and were not necessarily obtained after consultation with a listed organization. Therefore, it is suggested that these entries be used only as a general guide to initiating inquiries about research funding.

UNITED STATES

Air Force Aerospace Medical Research Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Air Force Flight Dynamics Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Air Force Human Resources Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Air Force Office of Scientific Research
Building 410
Bolling AFB
Washington, DC 20332

Air Force School of Aerospace Medicine
Brooks AFB
San Antonio, TX 78235

Air Force Systems Command
Director of Laboratories
Andrews AFB
Washington, DC 20334

Airline Pilots Association
Washington, DC

Army Aeromedical Research Laboratory
Box 577
Ft. Rucker, AL 36362

Army Aviation Research and Development Command
P.O. Box 209
St. Louis, MO 63166

Army Research Institute for Behavioral and Social Sciences
Room 6N12
5001 Eisenhower Avenue
Alexandria, VA 22333

Army Research and Technology Laboratory
DAVDL-AS
207-5 Ames Research Center
Moffett Field, CA 94035

Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

Department of Transportation
Federal Aviation Administration
800 Independence Avenue
Washington, DC 20591

Department of Transportation
Research and Special Programs Administration
Washington, DC 20590

Federal Aviation Administration
P.O. Box 25082
Oklahoma City, OK 73125

NASA Ames Research Center
Moffett Field, CA 94035

NASA Langley Research Center
Flight Management Branch
Hampton, VA 23669

National Institute of Mental Health
Bethesda, MD

Naval Aerospace Medical Research Laboratory
12475 Airblac Drive
Pensacola, FL 32506

Naval Air Development Center
Crew Systems Branch
Warminster, PA 18974

Naval Air Test Center
Patuxent River, MD 20670

Naval Air Systems Command
AIR-340F
Washington, DC 20705

Naval Biodynamics Laboratory
Box 29407
New Orleans, LA 70189

Naval Health Research Center
San Diego, CA 92152

Naval Medical R&D Command
Bethesda, MD 20014

Naval Personnel Research and Development Center
San Diego, CA 92152

Naval Sea Systems Command
Washington, DC 20362

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Pacific Missile Test Center
Point Magu, CA 93042

FRANCE

North Atlantic Treaty Organization
Advisory Group for Aerospace Research and Development (AGARD)
7 Rue Ancelle 92200
Neuilly Sur Seine

GREAT BRITAIN

Science Research Council

Social Science Research Council

Medical Research Council

U.K. Ministry of Defense

U.K. Department of Energy

Department of Employment

WEST GERMANY

Bundesministerium fur Forschung und Technologie
(Mo Research/Technology), D-5300, F.R. Germany

Bundesministerium der Verteidigung (Mo D)
D-5300 Bonn, F.R. Germany

Deutsche Forschungsgemeinschaft
(DFG, German Research Society),
D-5300 Bonn, F.R. Germany

CANADA

National Science and Engineering Research Council

NETHERLANDS

Ministry of Public Health and Environmental Affairs

ZWO Netherlands Organization for Pure Scientific Research
The Hague Ministry of Social Affairs

SECTION VI

SIGNIFICANT PUBLICATIONS IN MENTAL WORKLOAD

This section is a bibliography compiled from responses to a request to list those journal articles, books, reports, and conference proceedings which, in the opinion of the researcher, have made the greatest contributions to the understanding of mental workload.

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